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THE MIDDLE PALAEOZOIC GROUP OF JAPAN AND ITS BEARING ON HER GEOLOGICAL HISTORY*

By

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Abstract

The dated Middle Palaeozoic group of Japan is known to occur in close association with sheared granitoids and exotic metamorphic blocks along a certain kind of intensely disturbed zones in the non- or weak-metamorphosed Palaeozoic terrains. The Siluro-Devonian formations of the Kuma-Kii district of West Japan is divisible into four stages by lithology and palaeontology. The stage G_1 and G_2 are Wenlockian, the latter of which is characterized by *Falsicatenipora shikokuensis* and *Coronocephalus kobayashii*. The stage G_3 is lower Ludlovian and mainly composed of reef-limestone carrying *Schedohalysites kitakamiensis* and *Conchidium* cf. *knightii*. The uppermost, or the stage G_4, is a thick coarse sediment with a great amount of rhyolitic pyroclastics. It represents a transition from upper Silurian to middle (?) Devonian. A prevalent acidic volcanism during the early Devonian period of the Chichibu geocyncline was proven by the aid of palaeontology. The thick coarse sediments with granitic clastics in the lower division of the Sambagawa schist complex, which constitutes the metamorphosed axis of the Cretaceous Sakawa orogen, is presumed latest Silurian-early Devonian in comparison with the similar clastics of the stage G_4. The strong basic volcanism of the Tournaisian agrees with that of the middle part of the Sambagawa complex. A part of the Hida gneisses and Sangun schists, which are the metamorphosed axis of the Triassic Akiyoshi orogen, probably includes the Siluro-Devonian sediments judging from the lithology. The Silurian and Devonian sea in the Chichibu geosyncline was warm and several coral reefs were formed under various ecological conditions. The Outer Zone of West Japan was under rough water condition as a whole on one hand, while the Kitakami and Hida districts were rather calm on the other. In the Kuma-Kii district the reef-building was suddenly ceased at the end of Ludlovian when coarse sediments began to accumulate rapidly at the same time with violent acidic volcanism. Radiolarian rocks are common in the stage G_4 and lower Devonian formations in Southern Kitakami. The differences in lithology and thickness of the Middle Palaeozoic group in various districts presumably depend on a gentle crustal movement sympathetic with the Kwangsi disturbance in South China. Thick clastics of the upper Devonian Tobigamori series with *Leptophloeum* and other plant fragments are probably a product of this movement.

Preface

This is the principal paper which was presented in partial fulfilment of the requirement of the degree of Doctor of Science at the University of Tokyo in December 25, 1959. Under the direction of Professor Teiichi Kobayashi, this study was commenced in 1955 and carried out in the Graduate School of the University.

The followings are the auxilliary papers on which this study is based.

* Received April 26, 1960.

1) Geological Study of the so-called Mugishima Gneisses and their Surroundings
   (Abstract in Japanese).
        Jour. Geol. Soc. Japan, Vol. 61, No. 718, p. 364.   (July 25, 1955)
2) *Halysites kitakamiensis* Sugiyama from the Gotlandian Formation in the Kuraoka
   District, Kyushu, Japan.
        Japan. Jour. Geol. Geogr., Vol. 27, Nos. 2–4, pp. 133–141, Pl. IX.   (Oct. 25, 1956)
3) Axinite from Tochio, Gifu Prefecture (Miscellaneous notes in Japanese).
        Jour. Miner. Soc. Japan, Vol. 3, No. 1, p. 79.   (Oct. 31, 1956)
4) On the Septal Projection of the Halysitidae.
        Jour. Fac. Sci., Univ. Tokyo, Sect. 2, Vol. 10, Pt. 3, pp. 383–391, Pl. VI.
                                                                           (Dec. 10, 1957)
5) On the Classification of the Halysitidae, I.
        Ibid., Sect. 2, Vol. 10, Pt. 3, pp. 393–405.   (Dec. 10, 1957)
6) On the Classification of the Halysitidae, II.
        Ibid., Sect. 2, Vol. 10, Pt. 3, pp. 407–430.   (Dec. 10, 1957)
7) Japanese Halysitidae.
        Ibid., Sect. 2, Vol. 11, Pt. 2, pp. 91–114, Pls. VI–X.   (Nov. 30, 1958)
8) Fossiliferous Gotlandian Rocks in the Outer Zone of Southwest Japan (in Japanese
   with English Summary).
        Jour. Soc. Earthscientists and Amateurs of Japan (*Chigaku-kenkyu*), Vol. 11, No.
        1, pp. 33–46.   (Feb. 1, 1959)
9) Corallum Growth of the Halysitidae.
        Jour. Fac. Sci., Univ. Tokyo, Sect. 2, Vol. 11, Pt. 3, pp. 273–289, Pls. XII–XV.
                                                                           (Feb. 20, 1959)
10) Stratigraphy and Zoning of the Gotlandian Strata in the Outer Zone of South-
    west Japan (Abstract in Japanese).
        Jour. Geol. Soc. Japan, Vol. 65, No. 766, pp. 459, 460.   (July 25, 1959)
11) Discovery of a Devonian Ostracod in the Fukuji District, Gifu Prefecture, West
    Japan.
        Japan. Jour. Geol. Geogr., Vol. 30, pp. 39–51.   (Oct. 10, 1959)
12) Gotlandian Shelly Fauna from Southwest Japan (I). *Coronocephalus kobayashii*, a
    new Species from the Kuraoka District, Kyushu.
        Ibid., Vol. 30, pp. 71–88, Pl. VI.   (Oct. 10, 1959)
13) On the Taxonomic Position of *Favosites hidensis* and its Devonian Age.
        Ibid., Vol. 30, pp. 201–213, Pl. XVI.   (Oct. 10, 1959)
14) Gotlandian Stratigraphy of the Outer Zone of Southwest Japan (in Japanese with
    English Summary).
        Jour. Geol. Soc. Japan, Vol. 65, No. 770, pp. 688–700.   (Nov. 25, 1959)
15) Gotlandio-Devonian Systems in Korea and Northeastern China (in Japanese with
    English Summary).
        Ibid., Vol. 66, No. 775, pp. 263–278.   (Mar. 25, 1960)
16) The Middle Palaeozoic Formations in China and Korea, I. Korea and Northeast
    China.
        Japan. Jour. Geol. Geogr., Vol. 31, Nos, 2–4, pp. 165–183.   (Sept. 30, 1960)
17) The Middle Palaeozoic Formations in China and Korea, II. Northwest and South
    China.
        Ibid, Vol. 31, Nos. 2–4, pp. 219–239.   (Sept. 30, 1960)
18) Silurian Stratigraphy in Eastern Asia and Australia with Special Reference to the
    Encrinuridae.
                                                                           (MS)

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I.   Introduction

Geological history of the mountain building of the Japanese Islands was immensely illuminated by Professor KOBAYASHI in his " *The Sakawa Orogenic Cycle* " in 1941.   Three orogenic cycles, i. e. the Neo-Palaeozoic-Triassic Akiyoshi, the Jurassic-Cretaceous Sakawa and the Ôyashima cycle of the later period, were distinguished in the history.   Of them the former two are of prime importance for the remarkably zonal arrangement in the architecture of Honshu, Shikoku and Kyushu, and the last for that of Hokkaido and Sakhalin.

It must be remembered that these events have all happened during the later half of the whole history.   Putting aside the Cainozoic rocks, the most prevalent strata are the Permo-Carboniferous, and the Mesozoic ones are less extensive. In spite of the wide distribution, the Permo-Carboniferous history has been not much unveiled if compared with the well clarified Mesozoic and later parts. Least is known of the Silurian and Devonian stratigraphy and palaeontology, and none of the birth of the Chichibu geosyncline.   In order to solve the problem, the writer was engaged in field and laboratory works on the Middle Palaeozoic of Japan for eight years since he had been an undergraduate student of the Yokohama National University.   He surveyed almost all of the Middle Palaeozoic localities.   The geology of these in West Japan was mapped in scale of 1/5,000, 3/20,000, 1/10,000 or 1/50,000 so as to suit for the purposes.   The Middle Palaeozoic standard sequence of the Kuma-Kii district of the Outer Zone was taken from Yokokura-yama in Shikoku and Gion-yama in Kyushu.   As a result it became evident that its lower part rich in reef limestones is Wenlockian-early Ludlovian age on one hand, and that its upper part composed of coarse thick clastics with an immense amount of rhyolitic volcanic products represents the transition from Silurian to Devonian.   Here it is proven that the Devonian formation really exists in the Kuma-Kii district.

This succession is then compared with those of the Hida and Southern Kitakami districts.   Most salient is the extensive lower and middle Devonian acidic volcanism throughout the Chichibu geosyncline.   The differences of the ecological conditions among Hida, Kuma-Kii and Southern Kitakami are now well understood.

The axes of the three orogenic belts in Japan are represented by the metamorphosed complexes.   Their correlation to the non-metamorphosed formations bears crucial importance in order to decipher the development of the geosyncline.   This subject is also taken up here to elucidate as much as possible.

II.   Historical Review

The research in the Middle Palaeozoic of Japan was commenced with the discovery of Devonian rocks in the Kitakami district (YABE and NODA, 1933),

Subsequently, ONUKI (1937) found Silurian fossils in this district, and its fauna was monographed by SUGIYAMA (1939, 1940). But no comprehensive study has been done on the Devonian fauna, although some fragmentary notes were made by several authors.

In 1940 KOBAYASHI and IWAYA found *Halysites* in a limestone of Imosé, Kôchi Prefecture in Shikoku. It was the first that Silurian rocks were announced from the Kuma-Kii district. Prior to this YABE procured a specimen of *Favosites*-bearing limestone from the Yugyôji river, Ochi-machi, west of Imosé some fifty years ago, but it has never been reported before 1941 (SUGIYAMA, 1941; YABE and SUGIYAMA, 1942). Since the find of the Imosé limestone Silurian rocks have been successively found at other places in the Outer Zone which attain more than 14 localities as reviewed by the writer (1959a). In spite of the increase of fossil occurrences, no palaeontological study has been done except for SUIGYAMA's (1944) description of the Imosé fossils before the writer's paper on the Halysitidae (1956, 1958).

Of the geology of the Silurian area KOBAYASHI pointed out the common association of the fossiliferous masses with the Yokokura igneous rocks (KOBAYASHI and IWAYA, 1940; KOBAYASHI, 1941). According to him Silurian rocks were brought up from the depth to form the narrow belts simultaneously with the intrusive of the Yokokura ingeous group in the late Mesozoic period. ISHII and ICHIKAWA and others reported several Silurian occurrences associated with ingeous and metamorphic rocks, and called the chain of these rocks as the Kurosegawa zone (ISHII et al. 1952). Their interpretation of the zone is different from KOBAYASHI's, in that the zone is considered to have been completed by the end of the Palaeozoic period.

TACHIBANA's (1949) discovery of some late Devonian plants in Southern Kitakami is invaluable not only for the geology of Japan but also for the Devonian palaeogeography of Eastern Asia. With NODA, he recently revised the so-called *Spirifer* (*Trigonotreta*) *verneuili* MURCHISON of Japan, and gave a new name, *Cyrtospirifer yabei* (1959).

Incidentally, GOTTSCHE's Devonian *Spirifer* from Isé or Nagasaki (?) (1883) was erroneous, as already pointed out by YABE (1911, 1912).

In the Hida district of West Japan, KÔZU was the first to discover a *Favosites*-limestone at Fukuji, Gifu Prefecture (1911), but little attention had been paid until SUGIYAMA (1941) called it *Favosites* cf. *asper*. By some reason he did not discuss its geological age. Upon KOBAYASHI's suggestion KAMEI undertook the geological survey of the Fukuji area, and found the *Favosites*-limestone in question (1949). Its geological age was later considered to be late Silurian with the find of *Cheirurus* (KAMEI and IGÔ, 1955). Still later the trilobites were revised and their age decided at the early or middle Devonian by KOBAYASHI and IGÔ (1956). This trilobite horizon was separated from the *Favosites*-limestone or the Fukuji formation (s. str.) as the Takaharagawa formation.

Favosites has once been reported by GOTTSCHE (1884) from the fusulinid-bearing Permian Akasaka limestone of Central Japan. It might have been *Michelinia* or a similar advanced form of the Favositidae, if its occurrence be

correct. Subsequently HAYASAKA (1914) noted a specimen of *Michelinia* probably obtained from the Akasaka limestone.

III. Distribution

The Middle Palaeozoic rocks are distributed in Japan as shown in fig. 1. The Kitakami and Sôma districts are in Northeast Honshu, while the Hida district is in the Inner Zone of West Japan. In the Outer Zone a series of exposures are aligned in the Kuma-Kii district, i. e. from the western part of the Kii peninsula to central Kyushu through Shikoku Island. These strata are always steeply inclined, cut by faults and intruded by granitic rocks. The localities are listed below.

A: Northeast Japan (K in fig. 1)

Kitakami district of the Southern Kitakami mountains.

    1. Ôfunato area, Kesen-gun, Iwaté Prefecture.

    2. Nagasaka area, Higashiiwai-gun, Iwaté Pref.

Sôma district of the eastern part of the Abukuma mountains.

    3. Uwano, Kashima-machi, Sôma-gun, Fukushima Pref.

B: Inner Zone of West Japan

Hida district (H in fig. 1)

    4. Fukuji, Kamitakara-mura, Yoshiki-gun, Gifu Pref.

    5. Naradani, Kiyomi-mura, Ôno-gun, Gifu Pref.

    6. Ôtani and Isé, Izumi-mura, Ôno-gun, Fukui Pref.

C: Kuma-Kii District, Outer Zone of Southwest Japan (S in fig. 1)

Kii peninsula

    7. Nabaé-bana, Hirokawa-machi, Arita-gun, Wakayama Pref.
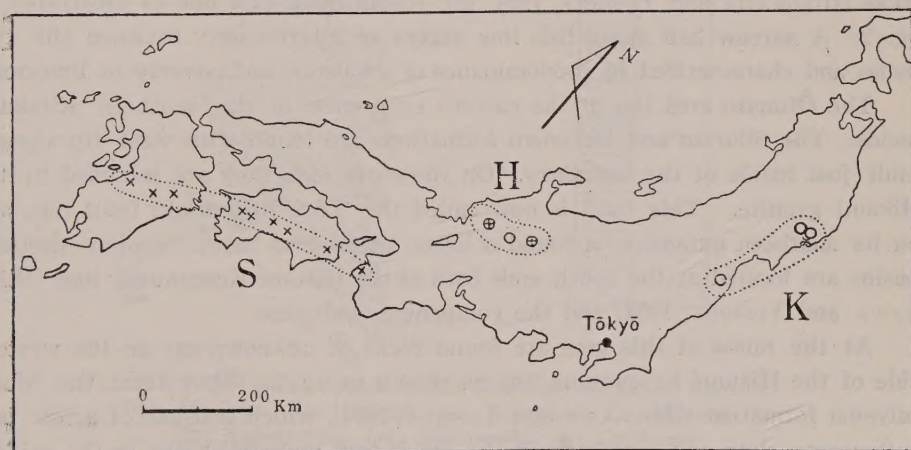
Figure 1. Distribution of the Middle Palaeozoic Rocks in Japan. H: Hida District, K: Kitakami and Sôma Districts, S: Outer Zone of Southwest Japan.
× : Middle Silurian-Middle Devonian, ⊕ : Upper Silurian-Middle Devonian, ○ : Middle-Upper Devonian.

Shikoku Island

8. Tatsukawa, Yokozé-machi, Katsura-gun, Tokushima pref.
9. Imosé, Hidaka-mura, Takaoka-gun, Kôchi Pref.
10. Yokokura-yama, Ochi-machi, Takaoka-gun, Kôchi Pref.
11. Matsu-tani, Yuzuhara-mura, Takaoka-gun, Kôchi Pref.
12. Mitaki-yama and Yoshinosawa, Kuroségawa-mura, Higashi-uwa-gun, Ehimé Pref.
13. Okanaru, Nomura-machi, Higashi-uwa-gun, Ehimé Pref.

Central Kyushu

14. Tsuzura, Ogata-machi, Ôno-gun, Ôita Pref.*
15. Gion-yama, Kuraoka and its arrounds, Gokase-machi, Nishi-usuki-gun, Miyazaki Pref.
16. Fukami and its surroundings, Shimomatsukuma-mura, Yatsushiro-gun, Kumamoto Pref.

See the writer's paper (1959a) for the exact points of the fossil localities in maps in scale of 1 : 50,000. In the Kuma-Kii-district there are many exposures of unfossiliferous Middle Palaeozoic rocks beside these localities.

IV. Geologic Structure

1. *Southern Kitakami and Abukuma District.*

The Palaeozoic group, especially the Upper Palaeozoic, in the Kitakami mountains is divisible into two lithic facies, i. e. the northern and southern Kitakami facies. The former is mainly composed of clayslate, sandstone and radiolarian chert, while the latter is rich in schalstein, limestone and conglomerate. Their boundary runs from Morioka to Goyôzan through the west of Kamaishi with the convexity on the northeast side. Several ultrabasic plutonic rocks (Hirokawa and Yoshida, 1954) are found along this line as illustrated in fig. 2. A narrow belt along this line makes an intermediary between the two facies and characterized by prodominance of schalstein and poverty of limestone.

The Ôfunato area lies at the eastern extremity of the southern Kitakami facies. The Silurian and Devonian formations are found with west dip along a fault just inside of the boundary. On the south side they are intruded by the Hikami granite. This fault is now called the Tôno-Kôjimisaki fault line, and on its southern extension is found a lower Cretaceous basin. Similar Mesozoic basins are located at the south ends both of the Hizumé-Kesennuma line (Hirokawa and Yoshida, 1954) and the companion fault line.

At the midst of this area are found rocks of unknown-age on the western side of the Hizumé-Kesennuma line as shown in fig. 2. They form the Mono-miyama formation (Hirokawa and Yoshida, 1954), which consists of acidic tuff, tuffaceonus slate and sandstone in the lower part, andesitic rocks in the middle, "schalstein", sandstone, slate and pale green siliceous rock in the upper part. Some conglomerate lenses probably at the top contain pebbles of chert, clayslate,

* Additionl new locality of the Silurian fossils was recently reported by Noda (1960) from Ôita Prefecture. Fide postscript 3).
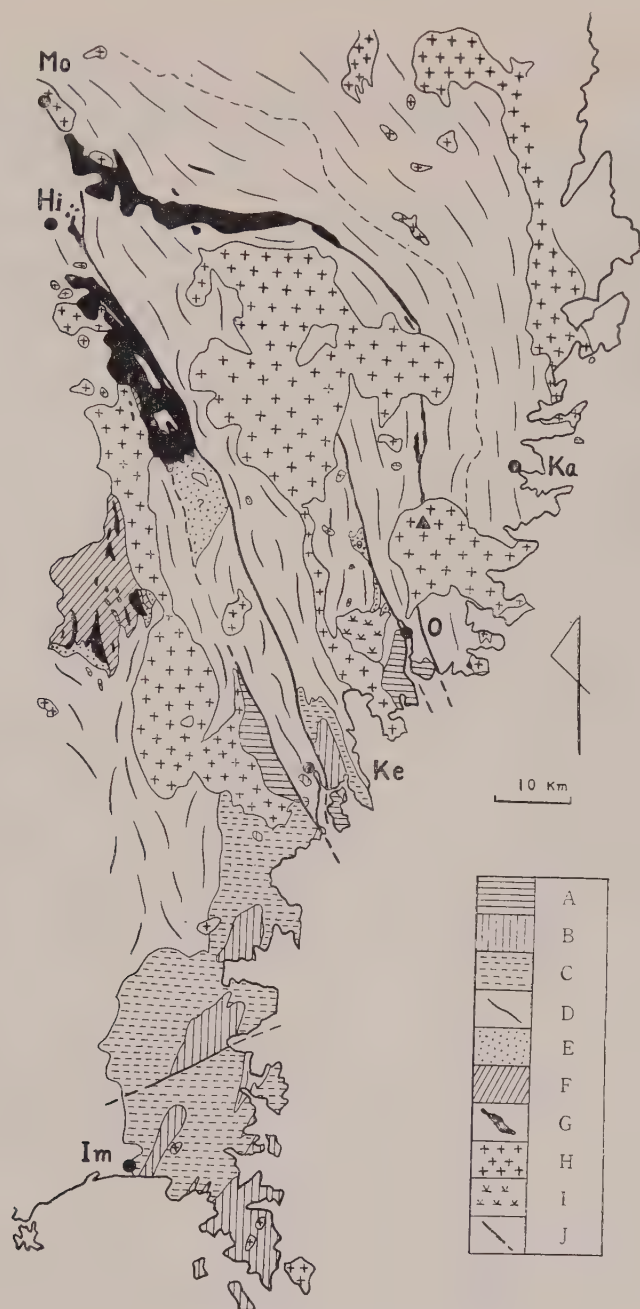
Figure 2. Geological outline of the Southern Kitakami district.
Mo: Morioka Hi: Hizumé Ka: Kamaishi O: Ôfunato
Ke: Kesennuma Im: Ishinomaki ▲: Goyô-zan

A: Cretaceous formations
B: Jurassic formations
C: Triassic formations
D: Upper Palaeozoic group and its structural trend
E: Silurian and Devonian formations
F: Shimoidé low metamorphic rocks
G: Ultrabasic rocks
H: Granites
I: Hikami sheared granitoid
J: Principal faults

andesitic rocks and granite. This formation is unfossiliferous but the acidic tuffaceous rocks strongly suggest middle Devonian for the lower part. This seems to be located near the axis of an anticlinorium. The lowest Carboniferous Yokota formation adjacent to the west is fossiliferous (ONUKI, 1956).

Combined with the upper Devonian of the Nagasaka district the Middle Palaeozoic rocks reveal a large anticlinorium of the Southern Kitakami mountains whose axis gently plunges southwards. It is cut by several faults with NNW-SSE trend, major ones of which are the Hizume-Kesennuma and Tôno-Kôjimisaki line. The Mesozoic basins are almost similar in size and tectonic trend among themselves as well as to folding of the Palaeozoic formations. The structural trend is, however, NNE-SSW in direction at the southern end of this district as shown in fig. 2.

In the Nagasaka area the upper Devonian formations occupy an axis of a synclinorium which dips gently to the south. Therefore, the Upper Palaeozoic terrain and the Mesozoic basins are fairly wide in the south. To the north of the Devonian area occurs the Motai formation composed of low metamorphic rocks (HIROKAWA and YOSHIDA, 1954; TACHIBANA, 1952). Its geological age is presumed older than late Devonian from the above structural situation.

Granitic rocks play an important rôle in Southern Kitakami. As seen in fig. 2, most granitic masses intruded almost concordantly with the major structure. Among them Hikami granite at the Ôfunato area is very heterogeneous and partly sheared (KANÔ, 1954). It intrudes not only the Silurian and Devonian but also the Permo-Carboniferous formations on the northern margin (SUZUKI, 1952)*. According to SENDÔ and YAMAGAMI (1953), it belongs to quartz diorite or adamellite. In the weak contact effect it is somewhat similar to the Yokokura igneous rocks. The so-called Tsubosawa gneisses composed of banded biotite-quartz gneiss, amphibolite, etc. are large masses caught in the Hikami granitoid. They are distributed in harmony with the lineation of the granitic rocks.

Though the exact age of this granitic intrusion is not yet decided, it is known that sheared granitic rocks named Kesengawa granodiorites intrude the Hikami mass and the Permian and lower Cretaceous sedimentaries affecting fairly strong contact metamorphism to them. Therefore the age of the Hikami intrusion is presumed post-Permian and pre-early Cretaceous by ISHII et al. (1956).

The lineation of the Hikami granite is parallel to the tectonic trend of the Palaeozoic formations whilst that of the Hirota granite, which is a member of the Kesengawa granodiorites, is parallel to the general strike of the lower Cretaceous strata (KANÔ, 1953).

The Arusu sheared granite which is considered a probable equivalent to the Hikami granite occurs at the northern end of the Middle Palaeozoic area.

Little is known of the structure of the upper Devonian Ainosawa series

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* SENDÔ and YAMAGAMI (1953) are of opinion that the granitic rock intruded into these Palaeozoic is not the Hikami proper but the Ôno granodiorite which is lithologically separable from the former.

in the northeastern Abukuma mountains. SATÔ (1956) noted that it is in fault contact with the Matsugadaira formation which is a metamorphic complex formerly considered lower Carboniferous (MINATO, 1952; HANZAWA, 1954). Petrographically it is similar to the Motai formation (KANÔ, 1958).

The Middle Palaeozoic of Sôma forms a narrow belt defined by a sheared zone on each side. Its boundary fault on the east with the Jurassic, of which the structural trend is parallel to the fault, runs almost meridionally. A Cretaceous half basin to the south is less effected this structural control. The western boundary fault of this zone is also parallel to the trend and accompained by mylonite and basic intrusives. The Yamagami metamorphic rocks and their equivalents of albite-epidote-amphibolite facies (in TURNER's sense, after GORAI, 1958, p. 80) are sporadically distributed along the eastern sheared belt. The Yakuki metamorphic rocks mainly composed of green-phyllite and schists are on the other hand narrowly exposed along the southern part of the western boundary fault in close association with weak or non-metamorphosed Palaeozoic strata. Although the above stated structural features in the eastern margin of Abukuma are much obscured by the younger granitic intrusions, the Middle Palaeozoic areas and the related Mesozoic basins are distributed in a similar way to those of Southern Kitakami. This part of Abukuma is called Futaba sheared zone by YAMASHITA (1957=by GORAI, 1958). This zone is possibly a result of strong modification of an anticlinorium (fig. 3).

It is interesting to see another tectonic zone with sheared granitoids and Palaeozoic rocks to occur at the south-
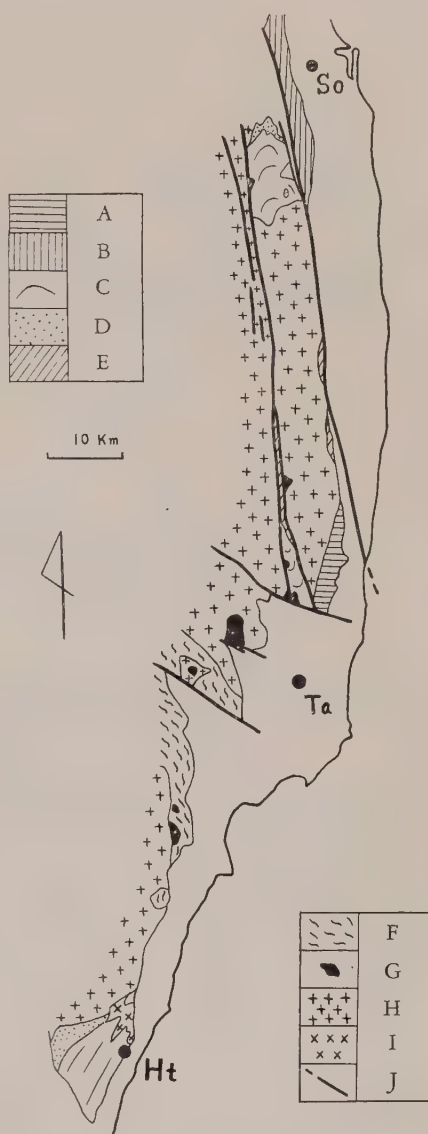
Figure 3. Geological outline of the Eastern Abukuma district.

So: Sôma, Ta: Taira, Ht: Hitachi
A: Cretaceous formations
B: Jurassic formations
C: Upper Palaeozoic group and its structural trend
D: Devonian formations
E: Yamagami and Yakuki metamophic rocks
F: Gozaisho-Takanuki metamorphic
G: Ultrabasic rocks
H: Granites
I: Sheared granitoids
J: Principal faults

Figure 4. Zonal Arrangement in

A : Cretaceous sediments higher than Gyliakian.
T : Median Tectonic Line.
B : Sambagawa metamorphosed belt.
M : Mikabu Tectonic Line.

ern end of the Abukuma mountains. According to Kuroda (1951, 1952, 1956),
the fossiliferous Viséan Kanayama metavolcanic complex (Fujimoto, 1924) and
older rocks in Hitachi area are intruded by the sheared granite which was pre-
sumably injected under somewhat dynamic condition. The Akazawa crystalline
schists which are overlain by the Carboniferous are possibly Devonian as dis-
cussed later. The sheared granite is said petrographically simllar to the Funazu
and Hikami granites (Kanô, 1956). The Hitachi area seems to belong to a part
of an anticlinorium similar to that of Southern Kitakami, although it is now
highly metamorphosed on the west side.

2. *Hida District.*

Here the Middle Palaeozoic formations are distributed along the Median
Tectonic Line of the Inner Zone which runs between the Hida gneiss complex
on the inner side and the non-metamorphosed Permo-Carboniferous formations
on the other. Some granitoids, such as the Funazu and Mugishima granites,
are found along the line. The Middle Palaeozoics are usually exposed along
faults and ultrabasic rocks intruded into faults. Some small masses of crystal-
line schists also occur within this disturbed zone.

Because of the limited exposures the structure of the Siluro-Devonian rocks
is not well known. They are all steeply inclined.

The Funazu granite and its correlatives look all heterogeneous by a great
deal of inclusions and become gneissose near the margin. Mafic minerals are
mostly converted into chlorite. Epidote is also an important constituent of the
granitoids. The contact effect by these granitic rocks is said to be not so
strong but vesuvianite-garnet rock is found in some places. The rock body and
the wall rocks are, however, often strongly sheared into mylonite and catacla-
site near their boundary. A remarkable example is the " green-schist " with

the Outer Zone of West Japan.

C: Chichibu terrain of the Kuma-Kii district.
D: "Mesozoische Mulde" and Kuroségawa Structural Zone. Black: Yokokura igneous rocks and associated Middle Palaeozoic rocks and metamorphic rocks. Locality numbers are collated to those in the text (p. 7).

pseudo-conglomerate between the Devonian Kiyomi series and the Mugishima granite (HAMADA, 1956; NOZAWA, 1959a). The so-called "Augengneiss" in the Hida gneiss complex near the Funazu and its correlatives is also considered similar shearing products (KOBAYASHI, H., 1957; NOZAWA, 1959a).

The Median Tectonic Line of the Inner Zone lies concealed largely beneath the Jurasso-Cretaceous Tetori series. Its conglomerate contains pebbles of the Hida gneiss and Funazu granite abundantly. Though it is not so remarkable as in the Southern Kitakami and Kuma-Kii mountains, a close relation of the Mesozoic basins with the tectonic line cannot be overlooked in this district. Namely, the Liassic Kuruma basin is at the north end of the Nagato line which is disposed at somewhat outer part than the Median Tectonic Line of the Inner Zone in the northeast of the Hida plateau (KOBAYASHI et al., 1957; KOBAYASHI, 1959). The Tetori series, on the other hand, are extensive in the gneiss and Palaeozoic region, but its lower marine sediments called the Kuzuryû sub-series mainly of the Malm—late Dogger age is restricted to occur along the Median Tectonic line in the western part of the plateau. The Itoshiro and Akaiwa sub-series above it are widely distributed both in the gneiss and Palaeozoic regions. The expansion of the Tetori basin may be comparable to the conversion of the Gyliakian basin to the later Cretaceous in the Kuma-Kii district.

3. *Kuma-Kii District, West Japan.*

The zonal structure is most distinct in the Outer Zone of Southwest Japan. The Sambagawa crystalline schist complex, which reveals the metamorphosed axis of the Mesozoic Sakawa orogen, runs in NE-SW direction from the Kii peninsula to Kyushu through Shikoku island. The non-metamorphosed or slightly metamorphosed Palaeozoic Chichibu terrain on the south side is separated from it at many places by a dislocation called Mikabu tectonic line. The so-
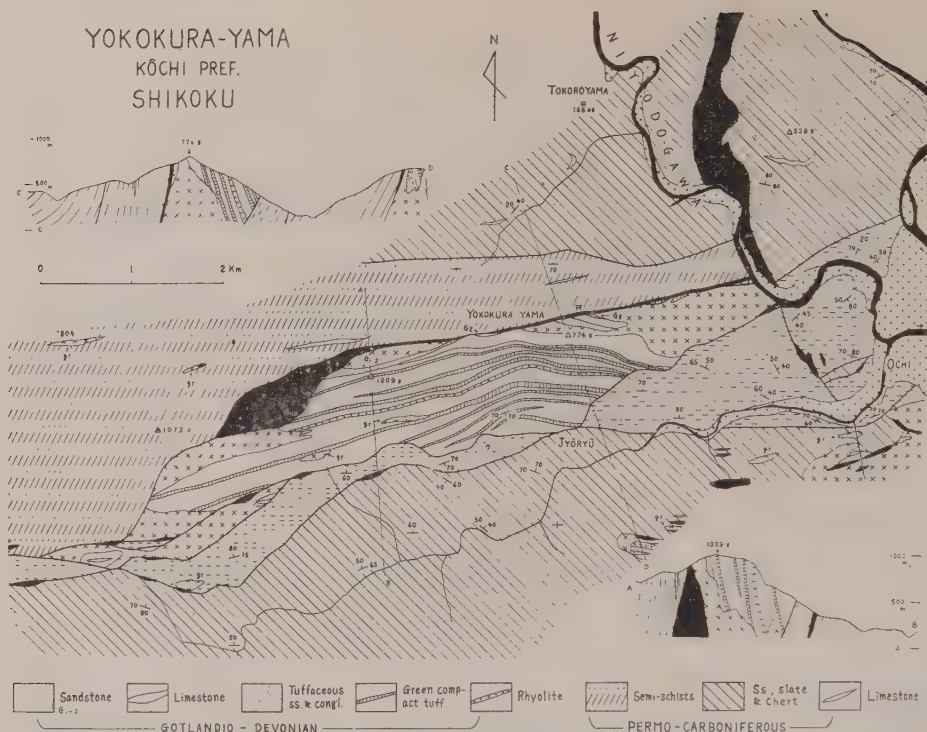
Figure 5. Geological map of Yokokura-yama area, Kôchi Prefecture, Shikoku (Loc. 10).

called Kurosegawa structural zone is represented by a chain of the distribution of Silurian and Devonian formations, crystalline schists, and the Yokokura igneous rocks in the Chichibu terrain.   Their distribution is inseparably to the "Mesozoische Mulde" by Naumann (1890) which is composed of the formations of various ages from middle Triassic to upper Cretaceous.   The Gyliakian and later ones are not restricted to the Chichibu terrain but occur widely on the north side as shown in fig. 4.   This conversion of the sedimentary basin during the late Cretaceous age is definitely a result of the Sakawa orogenic cycle.

The Yokokura ingeous rocks are mainly composed of sheared granitoids and serpentinite.   The granitic rocks are almost the same as the Hikami quartz-diorite in lithic characters.   Their contact metamorphism is slight.   They are often accompanied by the Terano metamorphic rocks in various sizes.   These Yokokura ingeous rocks were intruded into the Palaeozoic and in part into the Mesozoic formations, the youngest of which is the Carnian *Tosapecten-Halobia*-bed in the Sakawa basin where the contact relation is clearly observable (Hamada, 1959g).   But judging from the distribution, they probably intrude the lower middle Cretaceous sediments as already point out by Kurata (1941), although they are secondarily displaced at the boundary.

The Siluro-Devonian formations are found large xenolithic messes in the Yokokura igneous bodies.   At the Yokokura-yama and Gion-yama districts they are, however, fairly large as mapped in figs. 5 and 6.   There the Middle Palaeozoic formations were intruded by granitoids on the north side, while along

GION-YAMA
MIYAZAKI PREF.
KYŪSHŪ

Triassic ss. & shale | L.Cr. ss., sh.& congl. | M.Cr. ss., sh.& congl. | Granitic rocks | Serpentine | Alluvial deposits | ASO welded tuff & Pumice flow

└──── MESOZOIC ────┘ └──── INTRUSIVES ────┘
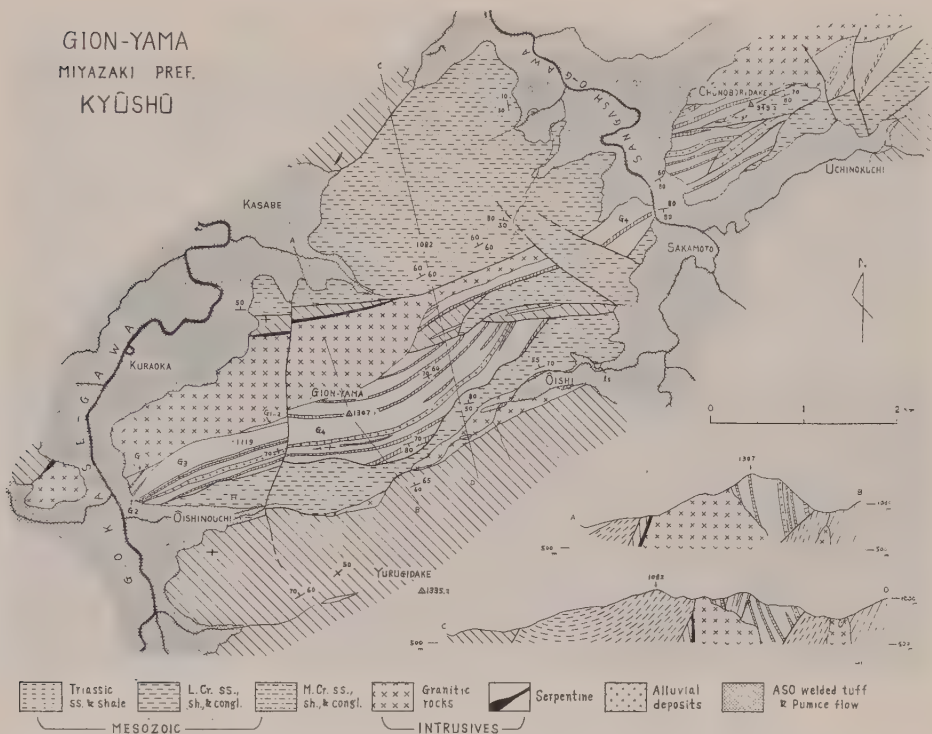
Figure 6. Geological map of Gion-yama area, Miyazaki Prefecture, Kyushu (Loc. 15).

the southern margin they were cut by faults or thrust themselves upon the Mesozoic with a steep angle. The Silurian and Devonian masses are highly disturbed in themselves into minute mosaic, but the original structure is fairly well preserved in such larger masses. The larger masses composed of massive limestone, hard compact tuff and massive tuffaceous sandstone in particular are so competent that they remained almost undisturbed by later movements. In the above two districts the strata strike nearly parallel to the axes of the masses and dip steeply to the south or southeast.

In conclusion, it can be said that the Middle Palaeozoic of Japan occurs as a rule in tectonic zones with usual association with sheared granitoids and some metamorphic rocks which are all together intricated. Those zones are also closely related to the Mesozoic structural basins, the so-called "Mesozoische Mulde" in the the Kuma-Kii district of Outer Zone for example.

The relation among the tectonic line, granitoids, and the Mesozoic basins reminds one of the "Tonalitzug" in the South Alps (WEBER, 1957). The tonalite series along the Iorio-Tonale Line are characterized by the linear distribution and strong mylonitization with "Augengneiss". They were intruded along the boundary between the gneiss of the "Bellinzona-Dascio Zone" and the "Insubrische Zone". The Triassic formation is distributed along the southern margin of the tonalite series. Though these structures were formed within the gneiss areas, the tonalite series with strong mylonitization along the tectonic line is not essentially different in genesis from the tectonic lines of Japan with

sheared granitoids such as the Yokokura, Funazu and Hikami granites.

Figure 7. Yokokura-yama, Shikoku.
The lowland in front is the Mesozoic Ochi basin. The
ridge is mainly composed of granitoid and the G₃ limestone.
(Photo. by T. HAMADA)

Figure 8. Limestone cliff at
Yokokura-yama.
(Photo. by T. HAMADA)

V. Topographic Significance

Topographically the above tectonically disturbed zones are, as a whole, low in relief. The Kurosegawa zone for example runs along the lowland in South Shikoku. The Sakawa basin is a typical instance. There several Mesozoic formations are aligned in belts being faulted and intruded by serpentinite. This disturbed zone is strongly dissected during the Cainozoic period to form the basins. The Palaeozoic areas on its north and south sides are less disturbed and stand high up. Most of the Yokokura igneous rocks which intrude this zone are so severely crushed that they are easy to decompose. The large granitoid mass is on the contrary, resistant to erosion. The hard Silurian and Devonian rocks incorporated with the granitoid in resistance. Yokokura-yama and Gion-yama are two good examples as shown in profiles on the

geological maps and fig. 7. They make steep slopes on the north and south sides and rises up more than 1,000 meters above the sea.

Among the Middle Palaeozoic rocks, the massive reef limestones (fig. 8), green compact tuffs and rhyolite beds are all cliff-makers.

The Median Tectocic Line of the Inner Zone in the Hida district and the structural belts in the Kitakami and Sôma districts reveal similar topography, although less striking than those of Kuma-Kii district of West Japan.

VI. Stratigraphy

This is a summary of the Middle Palaeozoic stratigraphy of Japan to which some palaeontological notes are added. Table 1 (p. 33) shows a chronology of the Middle Palaeozoic formations in three districts in Japan. The sequences are described in ascending order. In the following lists revised fossil names are marked with asterisks; names with apostrophes are the ones only listed; original author or reviser is bracketed behind a fossil name.

1. *The Kitakami-Abukuma District.*

The typical display of the Middle Palaeozoic is found in the Ôfunato area, Southern Kitakami district. Merit to many workers its sequence can be summarized as below.

i. *The Kawauchi Series* (Columnar section J)

a) *Favosites*-Limestone (30 m): its basal part intruded by granite; only a favositid, i.e. *Favosites* cf. *baculoides* (BARRANDE) procured from this limestone.

b) *Clathrodictyon*-Limestone (50 m): black, bituminous, and with many stromatoporoids; almost coeval with the superjacent *Halysites*-limestones as indicated by *Schedohalysites kitakamiensis.*

Actinostroma astroites (ROSEN)	(SUGIYAMA, 1939)
A. *sakariense* SUGIYAMA	(SUGIYAMA, 1939)
A. *variabile* SUGIYAMA	(SUGIYAMA, 1939)
Clathrodictyon onukii SUGIYAMA	(SUGIYAMA, 1939)
C. *tenuilaminatum* SUGIYAMA	(SUGIYAMA, 1939)
C. *giganteum* SUGIYAMA	(SUGIYAMA, 1939)
C. cf. *vesiculosa minutum* (ROMINGER)	(SUGIYAMA, 1939)
Clavidictyon columnare SUGIYAMA	(SUGIYAMA, 1939)
C. *japonicum* SUGIYAMA	(SUGIYAMA, 1939)
C. *delicatulum* SUGIYAMA	(SUGIYAMA, 1939)
Labechia sp.	(SUGIYAMA, 1939)
Stromatopora canaliculata SUGIYAMA	(SUGIYAMA, 1939)
Amphipora higutisawaensis SUGIYAMA	(SUGIYAMA, 1939)
A. *cylindrica* SUGIYAMA	(SUGIYAMA, 1939)
Schedohalysites kitakamiensis (SUGIYAMA)	(HAMADA, 1958)*
Halysites sp.	(SUGIYAMA, 1940)*
Favosites cf. *baculoides* (BARRANDE)	(SUGIYAMA, 1940)
F. *aspera* d'ORBIGNY	(SUGIYAMA, 1940)
F. *gotlandicus* forma *gotlandicus* LAMARCK ?	(SUGIYAMA, 1940)
Heliolites cf. *interstinctus* LINNÉ	(SUGIYAMA, 1940)
Propora affinis (BILLINGS)	(SUGIYAMA, 1940)

Figure 9. Columnar sections of the
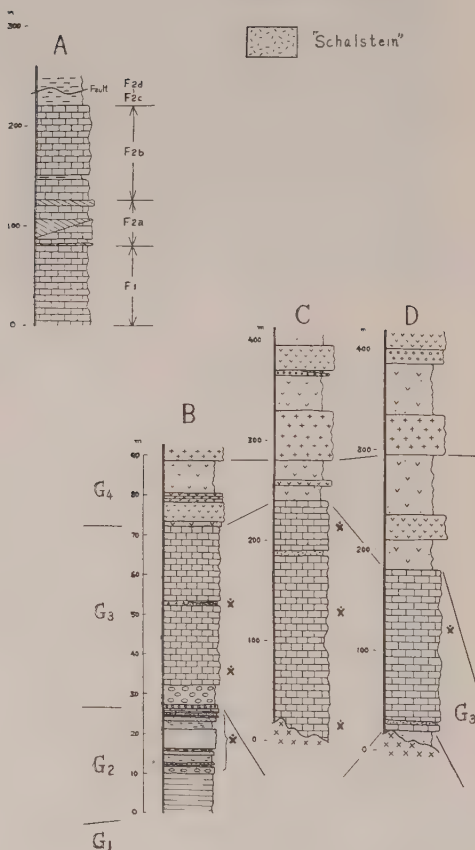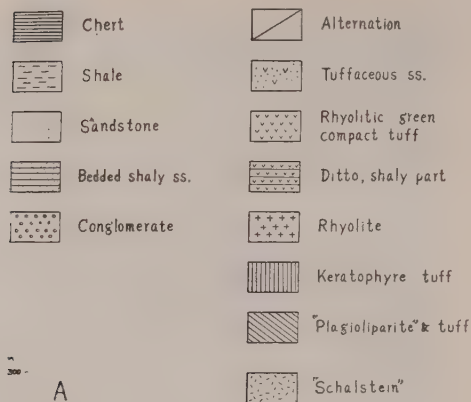
Localities

A : Ichinotani, Fukuji, Gifu Pref. (After
    KAMEI, 1955)

B : West of Gion-yama,
C : Northwest of Ôishinouchi Gion-yama,
D : Sedonotani,
E : East of Gion-yama, Miyazaki Pref.

F : Jyôryû-zawa and east ridge, Yoko-
    kura-yama,
G : North of Shima and east ridge,
H : North of Nakaôhira and east ridge,
    Kôchi Pref.

I : Subéridani, Tatsukawa, Tokushima
    Pref.

J : Hikoroichi area, Ôfunato-shi, Iwate
    Pref. (after MINATO et al., 1959a)
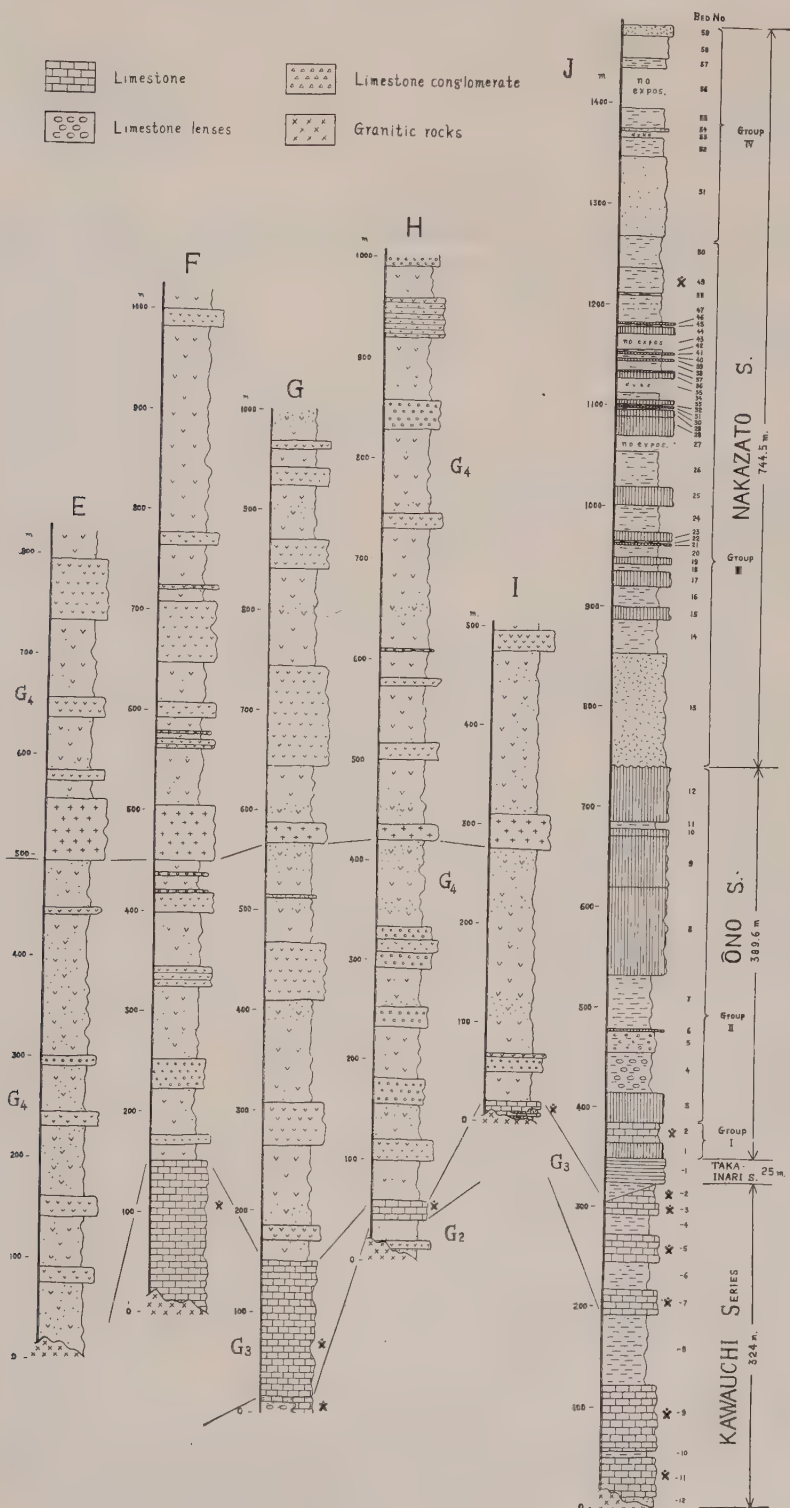
Aulopora sp.	(Sugiyama, 1940)
Tryplasma hayasakai Sugiyama	(Sugiyama, 1940)
T. h. multiseptatum Sugiyama	(Sugiyama, 1940)
Cyathophyllum ? sp.	(Sugiyama, 1940)
Monotrypella sp.	(Sugiyama, 1940)′
Solenopora sp.	(Sugiyama, 1940)′

<div align="center">(Total 27 forms)</div>

c) *Halysites*-Limestones: grey or black limestones and dark shale in alternation. Three fossiliferous limestone beds are exposed at Higuchi-zawa.

Actinostroma takainariense Sugiyama	(Sugiyama, 1939)
A. yabei Sugiyama	(Sugiyama, 1939)
Clathrodictyon regulare (Rosen)	(Sugiyama, 1939)
C. onukii Sugiyama	(Sugiyama, 1939)
C. sp.	(Sugiyama, 1940)
Kitakamiia mirabilis Sugiyama	(Sugiyama, 1940)
Labechiellata regularis (Sugiyama)[1]	(Sugiyama, 1939)*
Falsicatenipora japonica (Sugiyama)	(Hamada, 1958)*
Schedohalysites kitakamiensis (Sugiyama)	(Hamada, 1958)*
" *Halysites* " ? sp. by Sugiyama	(Hamada, 1958)*
Heliolites decipiens MacCoy	(Sugiyama, 1940)
H. bohemicus Wentzel	(Sugiyama, 1940)
H. arboreus Sugiyama	(Sugiyama, 1940)
H. cf. interstinctus Linné	(Sugiyama, 1940)
H. cf. barrandei (Hoernes)	(Sugiyama, 1940)
H. sp.	(Sugiyama, 1940)
Plasmoporella minutissima Sugiyama	(Sugiyama, 1940)
Propora affinis (Billings)	(Sugiyama, 1940)
Favosites gotlandicus forma *gotlandica* Lamarck ?	(Sugiyama, 1940)
F. aokii (Sugiyama)	(Kamei, 1955)*
F. sp.	(Sugiyama, 1940)
Palaeofavosites aspera (d'Orbigny)	(Sugiyama, 1940)*
Alveolites simplex (Barrande)	(Sugiyama, 1940)
Pachypora kitakamiensis Sugiyama	(Sugiyama, 1940)
Coenites triangularis Sugiyama	(Sugiyama, 1940)
C. sp.	(Sugiyama, 1940)
Aulopora sp.	(Sugiyama, 1940)
Syringopora cf. *tonkinensis* Mansuy	(Sugiyama, 1940)
Chaetetes sp.	(Sugiyama, 1940)
Helminthidium cf. *mirum* Lindström	(Sugiyama, 1940)
Tryplasma ozakii Sugiyama	(Sugiyama, 1940)
T. higutizawaensis Sugiyama	(Sugiyama, 1940)
T. takainariensis Sugiyama	(Sugiyama, 1940)
T. hayasakai Sugiyama	(Sugiyama, 1940)
T. sp.	(Sugiyama, 1940)
Nipponophyllum[2] *japonicus* Sugiyama	(Sugiyama, 1940)
N. yabei Sugiyama	(Sugiyama, 1940)
Spongophyllum yoshii Sugiyama	(Sugiyama, 1940)

1) *Labechiellata* Sugiyama, 1941b=*Labechiella* Sugiyama, 1939, non Yabe and Sugiyama, 1930.

2) Hill, D. (*Jour. Proc. Roy. Soc. New South Wales*, *Vol. 92*, 1958, p. 158) is of opinion that Sugiyama's *Nipponophyllum* may be congeneric with *Entelophyllum* Wedekind, 1927.

Cyathophyllum ? sp.	(SUGIYAMA, 1940)
Plasmophylloid coral	(SUGIYAMA, 1940)′
Calostylis sp.	(YABE, 1940a)′
Cystiphyllum aseptatum SUGIYAMA	(SUGIYAMA, 1940)
Rhyzophyllum lunulatum SUGIYAMA	(SUGIYAMA, 1940)
Solenopora ?	(SUGIYAMA, 1940)′

(Total 44 forms)

d) *Encrinurus*-Bed (5 m): frequent alternation of black shale and grey impure limestone.

Pentamerus ? sp.	(SUGIYAMA, 1940)′
Plectambonites ? sp.	(SUGIYAMA, 1940)′
Coronocephalus kitakamiensis SUGIYAMA	(SUGIYAMA, 1941a)

e) *Solenopora*-Limestone (4 m).

Kitakamiphyllum cylindricum (SUGIYAMA)[1]	(SUGIYAMA, 1940)
Tryplasma sp.	(SUGIYAMA, 1940)
Cyathophyllum ? sp.	(SUGIYAMA, 1940)
Monotrypella ? sp.	(SUGIYAMA, 1940)
Solenopora filiformis NICHOLSON	(JOHNSON and KONISHI, 1959)
Rothpletzella munthei (ROTHPLETZ)	(JOHNSON and KONISHI, 1959)

ii. *The Takainari Series* (150 m) (Columnar section J)

This conformably overlies the Kawauchi series, and is constituted of reddish purple, greyish black and green siliceous slates with abundant radiolarians in which the Sphaeroidea are predominant (SUGIYAMA, 1940, pl. 32 (20), figs. 7, 8). The reddish rocks seem tuffaceous.

iii. *The Ôno Series* (389.6 m) (Columnar section J)

Conformable with the preceding and mainly composed of keratophyre, quartz keratophyre, dacite, porphyrite, latite and their tuffs. These volcanics occupy 73 per cent of the whole thickness (MINATO and others, 1959a). The remainder consists of slates in reddish, bluish, dark grey and purplish colour. A few rounded pebbles of adamellite and granophyre 2 or 3 cm in diameter occur in fine-grained slate, i.e. the bed 5 of the columnar section (ÔKUBO, 1950). However, these granitic rocks are said probably to have been brought up as xenoliths in "schalstein" (SENDÔ in HANZAWA, 1954, p. 64). Only a thin limestone bed in the basal part is fossiliferous. *Atrypa* ? sp. occurs in the middle part, although its precise horizon is unknown (ÔKUBO, 1950).

Actinostroma cf. *tenuifilatum* PARKS[2]	(SUGIYAMA, 1941c)′
Clathrodictyon sp.	(YABE and SUGIYAMA, 1938)′
Favosites baculoides (BARRANDE)	(ÔKUBO, 1950)′
F. cf. *styriaca* (PENECKE)	(YABE and SUGIYAMA, 1938)′
Thamnopora cristata (BLUMENBACH)	(YABE and SUGIYAMA, 1938)′
T. sp.	(SUGIYAMA, 1941c)′
Pachypora sp.	(SUGIYAMA, 1941c)′
Coenites sp.	(SUGIYAMA, 1941c)′
Alveolites sp.	(YABE and SUGIYAMA, 1938)′
Thecostegites sp.	(MINATO et al., 1959a)′

1) Nom nov. by HILL (1956, f 312). Originally described as *Maia cylindrica*.
2) =*Actinostroma* sp. by SUGIYAMA, 1939.

Heliolites bohemicus Wentzel[1]	(Ôkubo, 1950)'
Tryplasma sp.	(Sugiyama, 1941c)'
Lindstroemia sp.	(Yabe, 1940a)'
Cyathophyllum sp.	(Yabe and Sugiyama, 1938)'
Spongophyllum vesiculosum Sugiyama (MS)	(Sugiyama, 1941c)'
Cymatelasma japonicum Sugiyama (MS) •	(Sugiyama, 1941c)'
Hexagonaria sp.[2]	(Yabe, 1958)'
Crinoid stem joints	(Yabe and Sugiyama, 1938)'

(Total 18 forms)

iv. *The Nakazato Series* (744.5 m) (Columnar section J)

In the series below the bed 46 keratophyric rocks occupy about 50 per cent of its thickness as shown in the columnar section, but almost none in the upper half. The lowest part comprises a thick andesitic layer which becomes coarse-grained toward the base and contains many rounded or flattened pebbles of " schalstein " and slate, 8 cm or so in maximum diameter. Therefore a weak disconformity was presumed between the Nakazato and the underlying Ôno series. The rounded andesite pebbles (2–3 cm in diameter) also occur in the beds 51 and 54* (Ôkubo, 1950). But no break is recognizable beneath these beds.

Favosites gotlandicus has been once procured from the basal part by Minato, Onuki and Yamada (Ôkubo, 1950; Onuki, 1956). According to Onuki, *Heliolites decipiens* var. nov. and *Stromatoporella* sp. (sp. nov.) are among the fossils from this part (Onuki, 1956, p. 26, footnote). Beside above a calcareous slate of the bed 49 is fossiliferous as listed below.

Heliolites sp.	(Ôkubo, 1950)'
Amplexoid corals	(Ôkubo, 1950)'
Bryozoa	(Ôkubo, 1950)'
Stropheodonta cymbiformis Swallow	(Ôkubo, 1956)
S. boonensis Swallow	(Ôkubo, 1956)
Meristella sp.	(Ôkubo, 1956)
Camarotoechia tethys (Billings)	(Ôkubo, 1956)
Atrypa desquamata mut. *japonica* by Sugiyama	(Sugiyama, 1942a)
A. pauciplicata Ôkubo	(Ôkubo, 1956)
Anoplotheca dorsosulcata Ôkubo	(Ôkubo, 1956)
Cyrtina heteroclyta Defrance	(Ôkubo, 1956)
Spirifer cf. *speciosus* (Schlotheim)	(Ôkubo, 1956)
Elytha fimbriatus (Conrad)	(Ôkubo, 1956)
Chonetes sp.	(Ôkubo, 1950)'
Schizophoria sp.	(Ôkubo, 1950)'
Paracyclus elliptica Hall	(Ôkubo, 1950)'
Modiomorpha cf. *subalata* Hall	(Ôkubo, 1950)'
Murchisonia sp.	(Ôkubo, 1950)'
Pleurotomaria sp.	(Ôkubo, 1950)'
Tentaculites sp.	(Minato et al., 1959a)'
Phacops okanoi Sugiyama (MS)[3]	(Sugiyama, 1944b)
P. nonakai Ôkubo	(Ôkubo, 1956)
Dechenella (Dechenella) minima Ôkubo	(Ôkubo, 1951)

---

1) =? *Heliolites* by Sugiyama, 1942b, p. 260, table 1.
2) =*Prismatophyllum* by Yabe, 1958, p. 214.
3) Probably *P.* cf. *latifrons* (Brongniart) in Yabe (1949a).
* Erroneously described as bed 53.

Scutellum (*Thysanopeltella*)[1] *paucispinosa* (Ôkubo) (Kobayashi, 1957)
(Total 24 forms)

The Takamori-yama area is the northernmost locality of the Middle Pala-eozoic rocks in this district whence Onuki and Matsuyama (1955) procured *Hexagonaria parvivesiculata* Eguchi and Onuki (MS)*, *Favosites* and *Heliolites*. The limestone bed there probably is equivalent to the bed 49. Suzuki's *Favosites* (1941) may come therefrom.

Sugiyama's *Phacops* zone at the Ômori-zawa yields *Phacops okanoi* (MS), *Proetus* sp., *Leptodesma* sp., *Atrypa reticularis* Linn., *A. desquamata* Sow., *Reticularia* sp., *Plectospirifer* sp., etc. It is also considered coeval with the bed 49 (Onuki, 1956).

v. *The Tobigamori Series*** (2,000 m) (text-fig. 10)

This is a black or grey slate series of great thickness in Nagasaka area, containing "schalstein" and porphyritic tuffs in a small amount (Minato et al., 1959a). The so-called schalstein is better called red slate from its microscopical characters (Gorai in Tachibana, 1952, p. 360, footnote). Several thin intercalations of conglomerate are called the "Natsuyama" conglomerate. On the road from Natsuyama to Shôhôji it contains the pebbles of hornblende-quartz schist, epidote-bearing hornblende-quartz schist, albite-epidote-hornblende schist, epidote-chlorite schist, epi-schalstein, mylonite, chert, sandstone, diabase prophyrite, granophyre and porphyroid. They attain 10 cm or more in diameter (Minato, 1946; Suzuki and Minato, 1946).

The following fossils occur in two horizons.

Cladochonus sp.		(Tachibana, 1952)′
Amplexus sp.		(Minato, 1952)′
Tetracoral		(Noda, 1934)′
Fenestella sp.		(Noda, 1934)′
Cyrtospirifer yabei Noda and Tachibana[2]		(Noda and Tachibana, 1959)
C.	*tobigamoriensis* N. and T.	(Noda and Tachibana, 1959)
C.	*t-. exsulcus* N. and T.	(Noda and Tachibana, 1959)
C.	cf. *breviposticum* Stainbrook	(Minato, 1955)′
C.	sp.	(Hayasaka and Minato, 1954)
C.	*sinense australis* (Maxwell)[3]	(Minato, 1955)′
Spirifer sp.		(Tachibana, 1952)′
Spiriferina sp.		(Minato, 1952)′
Brachythyris ? sp.		(Tachibana, 1952)′
Orbiculoidea sp.		(Tachibana, 1952)′
Athyris sp.		(Tachibana, 1950b)′

---

1) Originally described as *Thysanopeltis* by Ôkubo (1951).

2) =*Spirifer verneuili* by Yabe and Noda, 1933; *Spirifer* (*Trigonotreta*) *verneuili* by Noda, 1934; *Spirifer verneuili* by Suzuki and Minato, 1946; *Cyrtospirifer verneuili* by Tachibana, 1952, 1953; *Cyrtospirifer* cf. *kindlei* Stainbrook by Hayasaka and Minato, 1954.

3) =*Sinospirifer*.

* Probably *Columnaria* sp. in Onuki, 1956.

** =Nakakura formation by Tachibana (1950b) and Tobigamori formation by Noda (1934); Ômori series by Yabe and Sugiyama (1937).

Chonetes hardrensis (Phillips)[1]		(Yabe and Noda, 1933)'
Camarotoechia suzukii Tachibana (MS)[2]		(Noda and Tachibana, 1959)'
Waagenochoncha cf. *nummularis* (Winchell)[3]		(Noda and Tachibana, 1959)
Productus (*Linoproductus*) sp.		(Tachibana, 1952)'
P.	(*Avonia*) cf. *niger* Gosselet	(Tachibana, 1952)'
P.	(*A.*) *praelongus* Sowerby	(Tachibana, 1952)'
P.	? sp.	(Tachibana, 1952)'
P.	(*Buxtonia*) ? sp.	(Tachibana, 1952)'
Leptaena sp.		(Tachibana, 1952)'
Schuchertella sp.		(Tachibana, 1952)'
Schizophoria sp.		(Tachibana, 1952)'
Aviculopecten cf. *transversus* Sowerby		(Tachibana, 1952)'
A.	cf. *losseni* Koenen	(Yabe and Noda, 1933)'
A.	sp.	(Tachibana, 1952)'
Modiola sp.		(Tachibana, 1952)'
Sanguinolites sp.		(Tachibana, 1952)'
Phanerotinus ? sp.		(Tachibana, 1952)'
Murchisonia ? sp.		(Yabe and Noda, 1933)'
Nautilus sp.		(Minato, 1952)'
Crinoid stems		(Noda, 1934)'
Asteroidea		(Tachibana, 1952)'
Leptophloeum cf. *australe* (McCoy)[4]		(Tachibana, 1950a)
L.	cf. *australe* (McCoy) ?	(Tachibana, 1950a)
Cyclostigma sp.		(Tachibana, 1950a)
Lepidodendron ? sp.		(Noda and Tachibana, 1959)'

<div align="center">(Total 40 forms)</div>

Iwai has first found a limestone boulder with *Clathrodictyon somaense* Yabe and Sugiyama and *Amphipora* cf. *asiatica* Reed in a northwest valley between Ôashi and Zusahara of the Sôma district (Yabe, 1940). It was then thought to have been derived from the Permian Ôashi formation because they were reported as Permian by Yabe and Sugiyama (1927). Yabe (1940), however, predicted the probable older age of the Stromatoporoids when similar ones were discovered in the Southern Kitakami district.

In 1952, Satô found a brachipod fauna at Ainosawa, Tochikubo of the district. In distinguishing the following species among them Hayasaka and Minato (1954) concluded that the Ainosawa series is an equivalence to the Tobigamori series. This series is only 70 m orso in thickness and composed of grey, bluish or pale green clayslate, sandy slate and sandstone with intercalations of porphyritic tuff breccia, reddish purple tuff and reddish black slate beds. It is in fault contact with the Matsugadaira formation of unknown age which mainly consists of green siliceous phyllite, and probably overlain unconformably by the Carboniferous Tatéishi formation (*Siphonodendron* zone).

1) Fide Hayasaka and Minato (1954, p. 209).

2) = *Rhynchonella pleurodon* by Yabe and Noda, 1933; Suzuki and Minato, 1946; *Camarotoechia pleurodon* by Tachibana, 1952, 1953. Fide also Hayasaka and Minato 1954, p. 210.

3) = *Productus* (*Krotovia*) *nummularis* (Winchell) by Tachibana, 1952, 1953 = *Productella* by Tachibana, 1950b. Fide footnote in p. 447 by Tachibana (1952).

4) According to Sze (1952) *Leptophloeum australe* McCoy is synonymous with *L. rhombicum* Dawson.

Sinospirifer sinensis australis MAXWELL
         (HAYASAKA and MINATO, 1954)
Cyrtospirifer sp.
         (HAYASAKA and MINATO, 1954)
Camarotoechia ? sp.
         (HAYASAKA and MINATO, 1954)
Rhynchonellid
         (HAYASAKA and MINATO, 1954)
Chonetid
         (HAYASAKA and MINATO, 1954)
Crinoid stems   (SATÔ, 1956)'
Plant fragments   (SATÔ, 1956)'
         (Total 7 forms)

2. *Hida District.*

Since KÔZU's find (1911) of a favo-
sitid at Fukuji, this locality remained
untouched for years until KAMEI's sur-
vey in 1949. Based upon the *Favosites*
assemblage KAMEI (1952, 1955) divided
the Fukuji series into five fossil zones,
and thought that the lower or F_1 zone
is middle Silurian and the upper or F_2a–d
zones are upper Silurian. Adjoining
with IGÔ (1955), he reported *Cheirurus
sternbergi* from the top division of the
series and regarded it late Silurian in
age. KOBAYASHI and IGÔ (1956), however,
restudied the trilobite and concluded
that it is a new species of *Crotalocephalus*
which represents the Emsio-Couvinian,
instead of Silurian. By this reason the
Crotalocephalus-bearing Takaharagawa
formation was eliminated from the Fuku-
ji series. This was really the first that
the undoubted Devonian rocks were
festified in West Japan, although KAMEI

Figure 10. Columnar section of
the Tobigamori series.
(After MINATO et al., 1959a)
   a: Andesitic rocks
   s: Clayslate
   c: Conglomerate
   p: Porphyritic rocks

once noted a Devonian-type *Favosites* as a reworked pebble in the so-called
Murakami conglomerate that is now considered to be Permian age (KAMEI,
1949). Subsequently, the writer (1959f) emphasized Devonian aspects of *Favo-
sites hidensis*, which is a characteristic coral not only in the Takaharagawa
series but also in the Fukuji series (s. str.).

The similar *Favosites*-limestones were reported from other places of Fukui
and Gifu Prefectures by ISHIOKA and KAMEI (1950), FUJIMOTO, KANUMA and
MIDORIKAWA (1953) and MAEDA (1959). Palaeontology is made only on the Favo-
sitidae, on a cephalopod and a leperditiid ostracod, and most others are only
provisionally listed by KAMEI without descriptions (1952, 1955). Therefore the

fossil lists below show no more than a tentative determination.

i. *The Fukuji Series* (*s. str.*) (220 m) (Columnar section A)

A thick fossiliferous limestone with several intercalating beds of acidic tuff, which were described as plagio-liparite by Kamei. It is in fault contact with Permo-Carboniferous strata at the top and base.

The F_1 Zone (*Favosites baculoides* Zone) (60 m) : a heavily massive limestone. According to Kamei (1955) the following fossils were found in the upper black limestone.

> *Clathrodictyon tenuilaminatum, Clavidictyon columnare, Actinostroma vesiculosum, Amphipora cylindrica, Favosites baculoides, F. forbesi takarensis, F.* aff. *minor, F. asper, Parafavosites fukujiensis, Coenites triangularis, Pachypora* spp., *Aulopora* sp., *Chaetetes* sp., *Heliolites decipiens, H. bohemicus, Entelophyllum* sp., *Leptaena* cf. *rhomboidalis, Atrypa* sp., Actinoceroid, Orthoceroid, Gastropoda, Crinoid.

The F_2 Zone (*Favosites hidensis* Zone) : heavy limestone series with intercalations of acidic tuff and slate beds. Four subzones are in ascending order as follows :

The F_2a Subzone (*Favosites hidensis* Subzone) : alternation of acidic tuff and limestone.

> *Favosites hidensis, Coenites triangularis, Camarotoechia* sp., *Amphipora cylindrica, Holopea?* sp., *Hormotoma* sp.

The F_2b Subzone (*Favosites uniformis igoi* Subzone) : heavy limestone with a shale intercalation.

> *Favosites uniformis igoi, F. forbesi sugiyamai, F. gotlandicus, F. hidensis, F.* sp., *Heliolites fukujiensis, Syringopora* sp., *Coenites triangularis, Cystiphyllum japonicum, Entelophyllum dilatoseptatum, Clathrodictyon* sp., *Actinostroma* sp., *Amphipora* sp., *Strophonella oblonga, S. expansa, Amphistrophia* cf. *euglypha, Fardenia* sp., *Idioglyptus stigmatus, Leptaena* sp. *Fukujiella pingius, Atrypa reticularis, Pentamerus* sp., *Pterinea* sp., *Ctenodonta* sp., *Modiomorpha* sp., Crinoid.

" *Michelinoceras* " *hidense* Kobayashi (1958) was obtained probably from the basal part of this subzone.

The F_2c Subzone (*Favosites flexuosus* Subzone) : a thin calcareous shale bed.

> *Entelophyllum dilatoseptatum, Favosites flexuosus, Striatopora* sp., *Heliolites* cf. *decipiens, H.* sp., *Dalmanella* sp., *Parmorthis* sp., *Pentamerus* sp., *Cheirurus* sp.

ii. *The Takaharagawa Series* (Columnar section A)

This is formerly called the zone F_2d or the *Favosites ichinotaniensis* subzone by Kamei (1955). Emsio-Couvinian *Cheirurus* (*Crotalocephalus*) *japonicus* Kobayashi and Igô, *C.* (*C.*) sp. (Kobayashi and Igô, 1956), " *Leperditia* " *japonica* Hamada and *Favosites hidensis* Kamei (Hamada, 1959d, f) were described from this series. Beside Kamei (1955) listed many fossils as follows ;

> *Entelophyllum* sp., *Amplexus* sp., *Coenites* sp., *Rhynchotreta* sp., *Rhipidomella* sp., *Parmorthis* sp., *Camarotoechia* sp., *Delthyris* sp., *Cyrtina* sp., *Doleorthis* sp., *Dalmanella* sp., *Idioglyptus stigmatus, Leptaena rhomboidalis, Fardenia attenuata, Pentamerus* sp., *Atrypa reticularis, A.* cf. *tennesseensis.*

The stratigraphy of the other localities in the Hida district is not well known, but the following fossils are known to occur.

a) Ôtani valley, east of Tochio, Kamitakara-mura, Yoshiki-gun, Gifu Prefecture. Sandy shale, probably coeval with the Takaharagawa series.

Favosites hidensis KAMEI

(HAMADA, 1959f)

b) Ôbora-dani, west of Ôtani, Izumi-mura, Ôno-gun, Fukui Prefecture. Black, muddy limestone of the Kamianama group (probably an equivalence to F_2b zone of the Fukuji series).

Clavidictyon sp.	(OZAKI, 1957)′
Favosites hidensis KAMEI	(HAMADA 1959f)
Oborophyllum oboroense OZAKI	(OZAKI, 1956)
O. katoi OZAKI	(OZAKI, 1957)′
Brachiopod	
Gastropod	

c) Oisé-dani, Kamiisé, Izumi-mura, Ôno-gun, Fukui Prefecture. Black limestone of the Kamianama group; probably an equivalence to the Takaharagawa series.

Stromatoporoid	(HAMADA, 1959f)′
Favosites hidensis KAMEI	(HAMADA, 1959f)
Heliolites sp.	(HAMADA, 1959f)′
Cladopora sp.	(HAMADA, 1959f)′
Atrypa reticularis WILCKENS	(HAMADA, 1959f)′

Black limestone of the Kamianama group; probably an equivalence to the Fukuji series.

Clathrodictyon sp.	(ISHIOKA and KAMEI, 1950)′
Clavidictyon ? sp.	(ISHIOKA and KAMEI, 1950)′
Amphipora sp.	(MAEDA, 1958)′
Favosites aff. *aspera* d'ORBIGNY	(ISHIOKA and KAMEI, 1950)′
F. aff. forbesi EDWARD and HAIME	(ISHIOKA and KAMEI, 1950)′
F. forbesi takaharaensis KAMEI	(MAEDA, 1958)
F. sp.	(MAEDA, 1958)′
Coenites sp.	(MAEDA, 1958)′
Heliolites bohemicus WENTZEL	(ISHIOKA and KAMEI, 1950)′
Cyathophyllum sp.	(ISHIOKA and KAMEI, 1950)′
Brachiopod	(ISHIOKA and KAMEI, 1950)′
Crinoid stems	(ISHIOKA and KAMEI, 1950)′

iii. *The Kiyomi Series.*

In 1951, KANUMA has discovered a *Favosites*-limestone at Naradani, Kiyomi-mura, Ôno-gun, Gifu Prefecture. Subsequently FUJIMOTO, KANUMA and MIDORIKAWA (1953) proposed Naradani group for this formation and divided it into the lower or Hitotsunashi conglomerate schist and the upper or Hayashinohira formation* which is fossiliferous. They considered the former to be a basal conglomerate of the Silurian Naradani group which probably overlies the Mugishima gneiss to the north unconformably. Insofar as the writer can see, the so-called Mugishima gneiss intruded the Naradani group yielding a shattered zone with pseudo-conglomerate in the country rocks (1956). Recently KOBAYASHI,

* Fide postscript 1).

H. (1958) and Nozawa (1959a, b) expressed the same opinion.

The writer obtained the following succession in descending order.

Kiyomi Series
{
Upper sandstone member (430 m) with a prophyrite sheet (190 m)

Lower shale and sandstone member (220 m)* with porphyrite sheets (80 m)
}

The lower part merges gradually into the pseudo-conglomerate as it approaches the granite mass. The "Hitotsunashi conglomerate schist" is a metamorphosed facies instead of a stratigraphical unit. The name, Naradani, is preoccupied by a famous Jurassic formation in Shikoku (Kurata, 1940). "Kiyomi Series" is here proposed for its substitute name.

The followings were found in two fossiliferous limestone lenses in the middle part.

Clathrodictyon sp.	(Fujimoto et al., 1953)′
Amphipora sp.	
Favosites cf. *baculoides* Barrande	(Fujimoto et al., 1953)′
F. aspera d'Orbigny	(Fujimoto et al., 1953)′
Thamnopora? sp.	
Striatopora sp.	

Because of their strong deformation and recrystallization the identification cannot be warranted. These "*Favosites*" are, however, all thick-walled as often seen among the Devonian species. This characteristic as well as the great thickness of clastic sediments with a few amount of acidic tuffaceous rocks suggest that the Kiyomi series is not Silurian but Devonian, and probably younger than middle Devonian.

As already noted a part of the conglomerate schist is a metamorphosed conglomerate (Hamada, 1956). Its variegate colour strongly reminds the writer of the upper Devonian Natsuyama conglomerate. It may be also coeval with the enigmatic Murakami conglomerate with schist pebbles at Tochio, near Fukuji, Gifu Prefeture. Minato (1950) compared it with the Natsuyama conglomerate from its rock facies. The so-called Murakami conglomerate in other localities in Gifu and Fukui Prefectures are all Permian as proven by fusulinids.

3. *Kuma-Kii District.*

Various names were given for the Middle Palaeozoic rocks at different localities of this district. The writer intends to simplify the terminology by using the Gion-yama series for them. Hereafter G is its abbreviation.

i. *The Gion-yama Series* (G_1–G_4).

This is divided into four stages (G_1–G_4). The G_4 stage is presumably the Siluro-Devonian transitional formation but its top probably attains to the middle Devonian.

a) The Stage G_1.

Unfossiliferous sandstone probably with a thin green compact tuff bed in the middle part. The base is unexposed by faulting and intrusion of the Yoko-kura igneous rocks.

b) The Stage G_2 (25 m+) (Columnar sections B, D, G–I): composed of lime-

stone, calcareous sandstone, sandstone, tuffaceous sandstone, tuffaceous shale, sandy shale, conglomerate and so on. The following fossils were recorded from this stage.

Labechiellata regularis (SUGIYAMA)	(NODA, 1955)′
Catenipora ? sp.	(HAMADA, 1958)
Falsicatenipora shikokuensis NODA and HAMADA	(HAMADA, 1958)
Acanthohalysites kuraokensis HAMADA	(HAMADA, 1958)
Halysites sussmilchi ETHERIDGE	(HAMADA, 1958)
H. ? sp.	(HAMADA, 1958)
Favosites aspera d'ORBIGNY	(NODA, 1952)′
F. cf. *gotlandicus* LAMARCK	(ISHII, 1952)′
F. sp.	(NODA, 1955)′
Heliolites bohemicus WENTZEL	(NODA, 1955)′
Dania tsuzuraensis NODA	(NODA, 1960[1])
Cladopora sp.	
Syringopora sp.	
Tryplasma cf. *hayasakai* SUGIYAMA	(ISHII, 1952)′
T. sp.	(MIKI and EGUCHI, 1950)′
Zaphrentid	(ICHIKAWA et al., 1956)′
Lingula sp.	(MATSUMOTO and KANMERA, 1949)′
Orbiculoidea sp.	(ICHIKAWA et al., 1956)′
Eospirifer tingi GRABAU	(ICHIKAWA et al., 1956)′
E. cf. *tingi* GRABAU	(NODA, 1955)′
E. sp.	(ICHIKAWA et al., 1956)′
Spirifer cf. *bourgeoisi* MANSUY	(NODA, 1955)′
Orthid	(ICHIKAWA et al., 1956)′
Euomphalus sp.	(ICHIKAWA et al., 1956)′
Trochonema sp.	
Murchisonia sp.	
" *Pleurotomaria* " sp.	
Bellerophon sp.	
Tremagyrus sp.	
Mourlonia sp.	
Grammysia sp.	
Geisonocerina ? sp.	
Coronocephalus kobayashii HAMADA	(HAMADA, 1959e)
Encrinurus sp.	(ISHII, 1952)′
Octobronteus sp.	
Proetus aff. *latilimbatus* GRABAU	

(Total 36 forms)

c) The Stage G₃ (240 m) (Columnar sections B-D, F-I): massive, fossiliferous limestsne, mostly white but partly stained with tuffaceous materials in pale pink and green. No terrigenous rock is intercalated but a thin layer of volcanic rocks in this limestone. Corals are crowded especially in limestone breccia which presumably reveals a sort of reef talus. At Gion-yama, the G₃ stage is well exposed, and a thin volcanic layer is intercalated in it. As seen in columnar sections, the volcanic layer at the western margin of the limestone is composed of tuffaceous limestone breccia, and a lava flow at the middle of the exposure. Near Ôishinouchi the layer may be intercalated near the top. At

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1) Fide postscript 2).
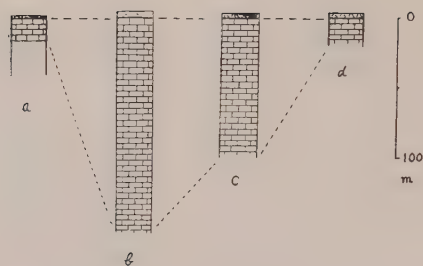
Figure 11. Accumulation of the G₃
limestone at Gion-yama (I).

An intercalation of andesitic rock
in the limestone was taken up for a
datum line.
a: West of Gion-yama (colum. B in
fig. 9)
b: Northwest of Ôishinouchi (colum.
C)
d: North of Ôishinouchi
e: Northeast of Ôishinouchi (colum.
D)
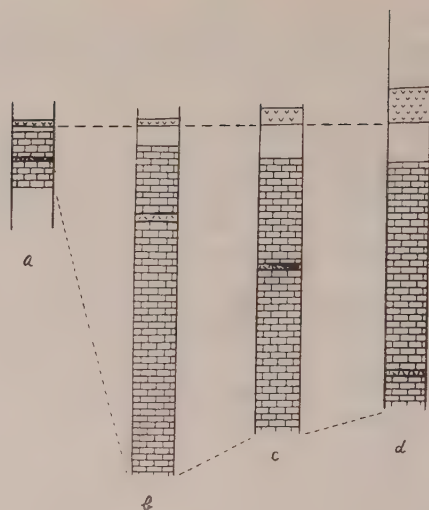
Figure 12. Accumulation of the G₃
limestone at Gion-yama (II).
The lowest green compact tuff of
the overlying G₄ stage was taken up
for a datum line.

the eastern extremity on the other hand, it is found in the basal part of the
limestone body.   This volcanic layer at the central portion of the distribution
is dark red, calcareous, sandy tuff with fine lamination. It is, however, mainly
represented by a lava flow in the eastern margin. These volcanic rocks are all
andesitic, and considered to be produced by a contemporaneous volcanism because
they are always intercalated in a limestone of the G₃ stage. No similar activiy
is known in other horizons of this district.

Taking the andesite for a datum line, the columnar sections can be correlated
as in fig. 11. It is interesting to see the difference in thickness of limestone
above and below the volcanic layers at places. These facts probably suggest
that the limestone has been accumulated with different rates, assuming that the
limestone body was not eroded away at the top. No evidence of such a denu-
dation can be detected in the overlying G₄ stage.   It is obvious that the
difference is original as there is no indication of strong erosion. At the time
of sedimentation the limestone was accumulated very slowly in the western part
as shown in the figure, because it was the margin of the reef. This difference
is more explicitly shown in fig. 12, where a basal green compact tuff of the G₄
stage is taken up for a datum line. This tuff layer is so extensive that it
serves as an excellent key in this district as seen in the geological map.

Most of the so-called Silurian fossiliferous formations in the Outer Zone are
contemporaneous with the G₃ stage. Though no precise analysis of the G₃ fauna
is as yet done except for the Halysitidae (HAMADA, 1958), the following fossils
were provisionally determined by various authors.

Labechia shikokuensis SUGIYAMA	(SUGIYAMA, 1944a)
Labechiellata regularis (SUGIYAMA)	(SUGIYAMA, 1944a)
Clathrodictyon sp.	
Falsicatenopora japonica (SUGIYAMA)	(HAMADA, 1958)
Schedohalysites kitakamiensis (SUGIYAMA)	(HAMADA, 1958)
Halysites cratus ETHERIDGE	(HAMADA, 1958)
H. *tenuis* HAMADA	(HAMADA, 1958)
H. *bellulus* HAMADA	(HAMADA, 1958)
" *Halysites* " ? sp. by SUGIYAMA	(HAMADA, 1958)*
Favosites gotlandicus LAMARCK	(ICHIKAWA et al., 1956)'
F. sp.	(ICHIKAWA et al., 1956)'
Coenites sp.	(SUGIYAMA, 1944a)
Heliolites sp.	(ICHIKAWA et al., 1956)'
Zaphrentis ? sp.	(SUGIYAMA, 1944a)
Tryplasma cf. *higutizawaensis* SUGIYAMA	(ICHIKAWA et al., 1956)'
T. cf. *multiseptata* SUGIYAMA	(ICHIKAWA et al., 1956)'
Zelophyllum sp.	(HAMADA, 1958)'
Kodonophyllum sp.	
" *Pycnostylus* " sp.	
Hedstroemophyllum ? sp.	(SUGIYAMA, 1944a)
Rhyzophyllum sp.	
Monotrypella ? *yabei* SUGIYAMA	(SUGIYAMA, 1944a)
Conchidium cf. *knightii* SOWERBY	(HAMADA, 1958)'
Rothpletzella gotlandica (ROTHPLETZ)	
Calcareous alga ?	(SUGIYAMA, 1944a)

(Total 25 forms)

d) The Stage G₄ (1,100 m) (Columnar sections B-I): overlying the G₃ stage conformably, this forms a thick series of tuffaceous rocks devoid of megafossils. Only radiolarian remains occur in tuff. Most remarkable is the predominance of acidic volcanic rocks. Namely, green compact rhyolitic tuff beds are numerous as shown in columnar sections. A rhyolite flow and its breccia are found near the middle part. Its large "high-quartz" phenocrysts are so characteristic that this rocks is easily perceptible, especially on the weathered surface. Accordingly it serves as a key. The sandstone bears also a large amount of tuffaceous material. These acidic volcanics occupy some 70 per cent in volume of the G₄ stage.

The other characteristic is abundance of granitic fragments in sandstone and conglomerate. The grains are usually angular or subangular and some pebbles attain more than 3 cm in diameter. Conglomerate beds are found in various horizones and merge laterally into tuffaceous sandstones.

VII. Geological Age, Correlation and Volcanic Activity

The oldest fossiliferous rock in Japan is of Wenlockian G₂ stage in the Kuma-Kii district, West Japan. *Coronocephalus kobayashii* from this stage at Kuraoka, Kyushu (HAMADA, 1959e) was seemed late Wenlokian or earliest Ludlovian. The type horizon of *C. rex* in China was previously presumed to be in the lower Hanchiatienian of latest Wenlockian or earliest Ludlovian as it is the most prevalent stage for the trilobite. But recent data indicate that the lower

Hanchiatienian belongs to the *Monograptus nilssoni* zone of the earliest Ludlovian (Hong, 1958) and that the type horizon of *C. rex* (Compil. tab. geol. China, Suppl., 1958) may be Valentian, if not lowest Wenlockian. Therefore it is not much deviated from the writer's presumption on the age for Hanchiatienian, but the age of *C. kobayashii* must be reconsidered.

C. kobayashii occurs from the G_2 stage which is overlain by the early Ludlovian G_3 limestone. It looks more advanced than *C. rex* in smaller granulation of the cephalon. The G_2 stage is possibly younger than late Valentian and definitely older than early Ludlovian. Its associates are middle Silurian *Octobronteus*, *Geisonocerina*, *Tremagyrus*, etc. Therefore it can be concluded that the oldest dated rock in Japan is Wenlockian, probably of early ∼ middle Wenlockian.

The age of the G_3 stage was already discussed elsewhere (Hamada, 1958, 1959f). *Zelophyllum* and *Conchidium* cf. *knightii* are the characteristics of the lower Ludlovian. In addition, *Kodonophyllum* newly found from the G_3 limestone in the Kuraoka district strongly supports the correlation of the G_3 stage with the *Zelophyllum-Kodonophyllum* stage in Gotland. *Schedohalysites kitakamiensis* is a common fossil among the G_3 stage and the *Clathrodictyon-* and *Halysites-* limestones (1–3) of the middle Kawauchi series. Therefore the middle Kawauchi in the Southern Kitakami mountains is exactly coeval with the G_3 stage of the Kuma-Kii district. The lower Kawauchi or the *Favosites* limestone probably represents earliest Ludlovian, but no keen index is as yet detectable.

The upper Kawauchi, i.e. the *Solenopora* limestone and *Encrinurus* bed are thought upper Ludlovian from the superposition and the more advanced aspect of *Coronocephalus kitakamiensis* than *C. kobayashii* (Hamada, 1959e). It is possible that they represent middle or late Ludlovian. The presence of the Encrinuridae excludes earliest Devonian age out of their dating.

The Takainari series and the G_4 stage are barren of megafossils. Radiolarians in them are not yet investigated, but the Cyrtoidea are apparently rare. Yamashita and others (1952) noted *Cenosphaera*-like form in vitric tuff of the G_4 stage. According to Ichikawa (1935) the Lower Devonian formations in the Southern Kitakami mountains contain many Sphaeroidea beside a negligible amount of the Cyrtoidea. Incidentally, a radiolarian faunule of the Tosayama red slate in Shikoku (Yehara, 1926), which includes *Staurosphaera*, bears Silurian aspect rather than Devonian (Kobayashi and Kimura, 1944).

The Ôno series was first considered to be Gedinnian by Sugiyama (1941, 1942), because *Prismatophyllum* and *Thamnopora* are Devonian members while *Tryplasma* and *Cymatelasma* are Silurian relics. According to Onuki (1956), however, its age is Coblenzian in view of the occurrence of *Favosites styriaca* which is abundant in the *Spirifer cultrijugatus*-bearing beds. Recently, Hill (1957) noted that most genera of Silurian Rugosa have disappeared before the early middle Devonian (lower Couvinian=*S. cultrijugatus* beds). As far as the writer is aware, *Tryplasma* survived until Coblenzian. Thus the *Tryplasma*-bearing limestone of the Ôno series cannot be younger than lower Devonian. As the limestone is in the basal part of the series, the upper half of the series possibly belongs to the lower middle Devonian.

Dechenella minima and *Thysanopeltella paucispinosa* suggest Givetian and Couvinian (Coblenzian) for the lower part of the upper Nakazato series (KOBA-YASHI, 1957). The former is accompanied by several species of *Phacops* (s.str.). This *Phacops* zone at Higuchi-zawa was tentatively correlated to SUGIYAMA and OKANO's *Phacops* zone at Ômori-zawa (1941) by ONUKI (1956). The latter zone is also considered Givetian on account of *Phacops* cf. *latifrons* and *Atrypa des-quamata* mut. *japonica* which is a close ally to *A. desquamata* mut. *hunanensis* and *A. d.* mut. *kansuensis* from the Miaoerhchuan (朝児川) bed in Kansu, China (SUGIYAMA, 1942). Therefore they are Givetian in age. The locality of *T. paucispinosa* is known not exactly.

EGUCHI and others consider from *Hexagonaria* sp. that the Takamoriyama limestone belongs to Eifelian (in ONUKI, 1956).

In the Hida district, Coblenzio-Eifelian is represented by *Cheirurus (Crotalo-cephalus) japonicus*-bearing Takaharagawa series (KOBAYASHI and IGÔ, 1956). The larger part of the underlying Fukuji series is probably lower Devonian, as *Favo-sites hidensis*, which is prevalent in this series and occurs also in the Takahara-gawa, bears Devonian aspects (HAMADA, 1959f). The lowest division of the series, however, might be latest Silurian. *Entelophyllum*, which is also characte-ristic of the Fukuji series, is a cosmopolitan, but survived until Gedinnian in Europe.

The Tobigamori and Ainosawa series characterized by several species of *Cyrtospirifer* are upper Devonian. *Leptophloeum* cf. *rhombicum* and *Cyclostigna*, which strongly suggest Famennian, are also obtained as drifts in the former

Table 1. The Middle Palaeozoic of Japan.

Ages \ Districts		Hida	Kitakami-Abukuma		Kuma-Kii	
Devonian	Famennian	Kiyomi Series	Tobigamori Series		(Unknown)	
	Frasnian					
	Givetian	— ? — (Unknown)	Nakazato Series		— ? —	
	Eifelian	— ? —				
	Coblezian	Takaharagawa Series	~~ ? ~~ Ôno Series		Stage G$_4$	
	Gedinnian	Fukuji Series				
Silurian	U. Ludlovian	— ? —	Takainari Series			Gion-yama Series
	L. Ludlovian	(Unknown)	Kawauchi Series	Solenopora ls. Encrinurus bed	Stage G$_3$	
	U. Wenlockian			Halysites ls. Clath. ls. Favosites ls.		
	M. Wenlockian		(Unknown)		Stage G$_2$	
	L. Wenlockian				Stage G$_1$	

series together with these spiriferids.

Hayasaka and Minato (1954) and Minato (1955) noted the occurrences of *Sinospirifer sinensis* Grabau emend. Tien *australis* Maxwell (=*Cyrtospirifer*) from these series. *Sinospirifer* is predominant in the Frasnian of China containing *Manticoceras*, *Yunnanella* and *Yunnanellina*. Therefore, it is a problem whether Frasnian exists in Japan or not. For its solution, palaeontology and stratigraphy of the Tobigamori and Ainosawa series are needed. But at any rate, they are undoubtedly Upper Devonian.

On the basis of the above chronology the Middle Palaeozoic of Japan is tentatively schematizedas as in table 1.

For the correlation of unfossiliferous strata with the standard sequence the lithic character is an aid. The upper Devonian Tobigamori series is characterized by fairly coarse sediments with reddish conglomerates which bear pebbles of several kinds of metamorphic and igneous rocks. This facies is extraordinarily rare for the Palaeozoic of Japan. The similar facies is met with in phyllonite of the upper Kiyomi series. Therefore this series may be presumed late Devonian. This dating is supported by the advanced form of the favositid accompanied by *Thamnopora* (?) in it. Likewise Minato contends from the lithology that a part of the so-called Murakami conglomerate in the Hida district and the reddish purple rocks in West Shikoku are the presumable equivalents to the Tobigamori series (1950a, b).

Incidentally, it is now proved by several fusulinids that the Murakami conglomerate which has been considered Silurian is mostly Permian.

The lower half of the Devonian formation and a part of the upper Silurian are characterized by the prevalence of acidic volcanic facies through the Chichibu geosyncline. According to Minato and others (1959a), it is composed in the Southern Kitakami mountains of keratophyre, quartz-keratophyre and their tuffs, dacite and porphyrite, beside some andesitic rocks.

In the Hida district, Kamei noted an occurrence of fine-grained rhyolite and its tuff in the Fukuji series under the name of "plagio-liparite". Prior to him, Shibata (1944) called attention on the occurrence of "liparite-tuff" in association with *Favosites*-limestone at this locality. He mentioned that the tuff is similar to that of the "Silurian strata" of other localities in Japan.

The G_4 stage at the Siluro-Devonian transition in the Kuma-Kii district of West Japan is also remarkably characterized by the acidic volcanic materials. They were described by several authors. The following descriptions are given for these rocks.

Rhyolite: phenocrysts composed of "high quartz", orthoclase and oligoclase. Feldspars always suffered from strong kaolinitization and sericitization. Quartz phenocryst 13 mm or so in the maximum diameter, and often corroded. Mafic minerals so completely chloritized that original minerals are indistinguishable. Ichikawa and others (1956) recorded small crystals of augite. Groundmass consists of quartz and albite (?) grains and a vast amount of minerals of chlorite group. Some parts show brecciated structure, blocks of which being from bean to cobble size. Accessory minerals are apatite, zircon, iron ores, etc. Rhyolite tuff: green compact chert-like rocks characterized by conchoidal fracture;

typical vitroclastic texture sometimes recognized; precise mineral composition indeterminable because of small grains, but seemingly same as above rhyolite; often containing ill-preserved radiolarians.

The volcanic activities shown by the rocks above mentioned in the South-ern Kitakami, Hida and Kuma-Kii are almost same in their natures, and most violent in early Devonian. A similar activity is also known in the lower Per-mian (MINATO et al., 1959c). But it is almost negligible in amount. Therefore it bears high possibility that some acidic rock-bearing unfossiliferous Palaeozoic formations and their metamorphosed equivalents are early—middle Devonian, if not the latest Silurian. Then, the Ubayama formation (after WATANABE and Kô, 1942=Monomi-yama formation by HIROKAWA and YOSHIDA, 1954) with rhyo-litic layers in the northern part of the Southern Kitakami is possibly middle Devonian. The presence of thin conglomerate beds at its upper part is strongly suggestive of upper Devonian for that part. The series is situated at the core of an anticline on the western wing of the Southern Kitakami anticlinorium (fide p. 9, fig. 2).

The Motai* and Matsugadaira series respectively in Southern Kitakami and Northern Abukuma are each located on the northern margin of the south-erly plunging synclines of the anticlinoria. Structurally they are all lower than the fossiliferous upper Devonian, though their boundary is in a fault. The two series are characteristic in their weak-metamorphosed "green siliceous rocks" and several rhyolitic and dacitic intercalations (SATÔ, 1956; KANÔ, 1958). Thus they may include the lower half of the Devonian system.

The Akazawa formation at Hitachi, Southern Abukuma is composed of schists probably originated from acidic volcanic rocks and their clastics (KURODA, 1956, etc.) and believed now to be Devonian. It is an important fact that the formation is conformably overlain by the fossilferous Ayukawa formation of early Carboniferous age.

Of the probable Siluro-Devonian equivalents in the Sambagawa metamorphic complex, the reader is referred to chapter IX.

In summary unfossiliferous Devonian strata are listed below:

1) Sangun metamorphic rocks in Eastern Chûgoku. Pre-Carboniferous (MITSUNO, 1959).

2) Staurolite schist in Northern Hida (ISHIOKA and SUWA, 1956).

3) Akazawa formation at Hitachi. Pre-low. Carboniferous (KURODA, 1956).

4) Matsugadaira formation in Northern Abukuma. Pre-up. Devonian? (SATÔ, 1956).

5) Shimoidé formation in Southern Kitakami. Pre-up. Devonian? (TACHIBANA, 1952).

6) Ubayama formation in Southern Kitakami. Pre-low. Permian? (HIRO-KAWA and YOSHIDA, 1954).

7) Pre-Etreoungtian (?) Formation, South of Ôtomo-machi, Tôno City, Iwaté Prefecture. (FUKADA, 1953 MS; in ONUKI, 1956, p. 21).

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* =Shimoidé formation by WATANABE and Kô, 1942. According to SHIMAZU (1954), this formation gradually changes into *verneuili*-bearing upper Devonian slate (p. 78).

The last is mainly composed of sandy shale in the upper part (250 m), and sandy shale, siliceous slate, "schalstein" in the lower (200 m).

VIII. Palaeoecology and Lithic Facies

Little attention has been paid on the ecology of the Japanese Silurian and Devonian biota in spite of the profusion. It is probably because of limited exposures of the fossil-bearing rocks by tectonic control. They are all steeply inclined, cut by faults, or intruded by igneous rocks at places. Under this circumstance it is difficult to trace the lateral change of the lithic or faunal facies.

The Niagaran and Baltic reefs have been studied in detail by many workers. As they were all built on stable grounds, they are undamaged by lateral compression. The Japanese reefs on the contrary, had been built in the Palaeozoic Chichibu geosyncline which devoloped into the orogenic belts in the Mesozoic era. As the result the structure of the reefs were much modified.

Efforts were made in recent years to gather available data to clarify their ecological conditions. This is an introductory note to my study along the trend.

1. *The Stage G_2.*

This stage at the following four places in the Outer Zone includes various rocks.

     1) Yokokura-yama, Kôchi Prefecture, Shikoku (Loc. 10)
     2) Okanaru, Ehimé Pref., Shikoku (Loc. 13)
     3) Gion-yama, Miyazaki Pref., Kyûshû (Loc. 15)
     4) Fukami, Kumamoto Pref., Kyûshû (Loc .16)

In the second and fourth districts it is composed of green compact shaly tuff and tuffaceous sandstone. *Encrinurus* sp., *Eospirifer tingi*, gastropods and pelecypods are known from the second locality and "*Lingula*" sp. and gastropods from the fourth. In the first and third districts it is represented by sandstone, tuffaceous sandstone, shale, sandy shale conglomerate and limestone, and richly fossiliferous.

As shown in the columnar section B, this stage at Gion-yama is rich in arenaceous matter. Small nodules of impure limestone (1–4 cm in diameter) are characteristic of this bed. Three horizons are especially fossiliferous. The lower one is characterized by *Acanthohalysites kuraokensis* and the middle by *Coronocephalus kobayashii*. *Falsicatenipora shikokuensis* is found both in the middle and upper horizons. In addition, *Lingula* sp., *Geisonocerina*? sp., *Tremagyrus* sp. *Murchisonia* sp., *Octobronteus* sp., etc. were obtained from the middle part. Not only the cranidia, free cheeks and pygidia but also hypostomata and thoracic segments of *Coronocephalus kobayashii* are crowded and fairly well preserved in the impure limestone nodules. Therefore the transportation of the trilobite shells after death by current would be negligible. According to Lowenstam (1957), *Encrinurus* is a typical quiet water dweller in the initial stage of reef-building and absent in rough-water populations high above the reef. The ecological condition of the G_2 stage agrees with his interpretation. Delicate colonies of branched *Cladopora* rich in the upper horizon did not suffer from

destruction. They are associated with small patellate tryplasmatids. These delicate fossils show the tranquility of water in the inner reef.

At Yokokura-yama are known two rock exposures of this stage. The western one consists of brownish grey limestone and arenaceous limestone with green tuffaceous material. These limestones are typical of fragment-limestone by HADDING (1958, p. 17). Coral fragments and brachiopods are aggregated as limestone builders, and tetracorals are rare. It is remarkable that *Falsicatenipora shikokuensis* of these limestones forms massive, hemispherical or encrusting colonies but it is trochoidal in impure limestone nodules in sandy shale at Gion-yama as already illustrated (HAMADA, 1958). This combined with the coarse rock facies vindicates that the limestones at Yokokura-yama are sediments in slightly rough water. Angular quartz grains filling up the space among coral tubes are characteristic features as shown on plates 7 and 9 (HAMADA, 1958).

The lithic and faunal facies of the G₂ stage as a whole indicate rather quiet water in the initial growth stage of the reef. No true reef is so far known in this stage. It represents a prelude to the vigorous reef-building of the forth-coming G₃ stage.

2. *The Kawauchi Series and the Stage G₃.*

The lower Ludlovian stage G₃ is represented by limestones in the Kuma-Kii district and by limestones and shales in the Southern Kitakami mountains. The former limestones are almost white or pale in colour, scarcely argillaceous and contain tuffaceous material in a small amount, while the latter limestones are always stained in black or dark grey colour by carbonaceous matter or other impurities. The difference may be attributable to the different reef-building sites (HAMADA, 1958, p. 94).

Although these reef limestones are rich in stromatoporoids, tabulata and colonial tetracorals, the former limestone is quite massive, partly brecciated and lacks intercalations of other sediments, whereas the latter is often intervened by black shales. Therefore it can be presumed that the limestones in the Kuma-Kii district have been deposited in rough water facing an open sea where the argillaceous matter could not settle. The Kitakami area was, however, probably situated on the inner side of the reef in slightly rough water condition.

Neither pisolite nor fine-grained carbonate facies of back reef has so far been known in the Kuma-Kii district. The limestones there merge laterally into coarse calcareous or tuffaceous sandstone but not into shale or marl. The absence of marginal reef facies also suggests that the reefs in question were barrier reefs under strong surf action on a long swell of sea bottom.

Though the faunal analysis of the G₃ limestone in the Outer Zone is not yet accomplished, it is beyond doubt that these limestones are mainly composed of halysitids, favositids, heliolitids, and stromatoporoids. These corals and hydrozoas are all massive or encrusting forms. Some slender tetracorals, such as *Zelophyllum* and "*Pycnostylus*" also take a rôle in the architecture of the reefs forming large phaceloid colonies. Neither small discoid nor patellate tryplasmatid is found but fairly large cylindrical or trochoidal forms exist in the lime-

stones. This coral assemblage clearly shows the rough water environment of the reef.

Accompanied by tetracorals, a thick-shelled *Conchidium* cf. *knightii* was found in compact pale grey limestone at Gion-yama. According to LOWENSTAM (1957) this genus is a leading reef-dweller, best suit for the wave-exposed outer margins of the reefs or the highly agitated water facies, as exemplified in the Niagaran reefs of North America. It is noteworthy that the brachiopod is unknown from the reef limestones of the Kawauchi series which correspond to the G_3 limestones.

The Kawauchi series is composed of coralline limestones and shales. The middle part, or the *Halysites*-limestones (1-3), and probably the underlying *Clathrodictyon*-limestone are correlative to the stage G_3 of the Outer Zone. These limestones are dark grey or black in colour and highly bituminous. The arenaceous matter, however, does not play an important rôle as a constituent. These facts indicate that they were accumulated not in rough water as the limestones of the G_3 but near the reef flat where detrital materials were scarce. Because there are no shells like gastropods, pelecypods and brachiopods in these limestones, it is presumable that they are deposited neither at the back reef nor at the fore reef. Furthermore, the limestone breccia or the reef talus, which often characterizes the reef front and its seaward extensions in very rough water, is so far unknown in the Kitakami district.

The upper part of the series is, on the other hand, mainly composed of limestones with a small amount of shale, and divisible into two parts by fossil contents. The lower division is *Encrinurus*-bed characterized by large *Coronocephalus kitakamiensis*. Precisely, this is a thin-bedded alternation of black shales and grey impure limestones, and becomes considerably sandy near the base. Beside the trilobites, *Pentamerus* ? sp. and *Plectambonites* ? sp. are recorded from this bed. It may represent a shelly fauna of the reef flat or shallow back reef facies.

The uppermost bed of the Kawauchi series is a *Solenopora*-limestone with *Solenopora filiformis*, *Monotrypella* ? sp., and some tetracorals. Calcareous algae, especially of massive forms such as the Solenoporacea, are said to be a characteristic ingredient in the Lower and Middle Palaeozoic reefs, as exemplified by the Gotland reefs (HADDING, 1941). Another calcareous alga of the *Solenopora*-limestone is *Rothpletzella munthei* (JOHNSON and KONISHI, 1959) which is an encrusting-type " *Pilothrix* ". A thin coating of " *Pilothrix* ", probably *Rothpletzella gotlandica*, is found on the wall surface of *Kodonophyllum* sp. from the G_3 limestone at Gion-yama, in the Kuma-Kii district. It is an important fact that " *Sphaerocodium* ", which is thought to be a morphological variation of a certain alga corresponding to " *Pilothrix* " and is more abundant in the marlstones of lower parts of the reef flanks in the Gotland reefs, is absent not only in the limestones of the G_3 stage but also in the Kawauchi series.

Stromatoporoids are not so important as tabulata for the reef-building of the G_3 limestones of the Kuma-Kii district. Fragmentary colonies were found in some parts of the limestone intermingling with coral stocks. The basal attach-

ment seems to be mostly on the solid substratum. Their growth forms are somewhat irregular whithout any distinct colonial hump. A few slender club-shaped stromatoporoids are found in some parts of the limestones as shown in fig. 13.
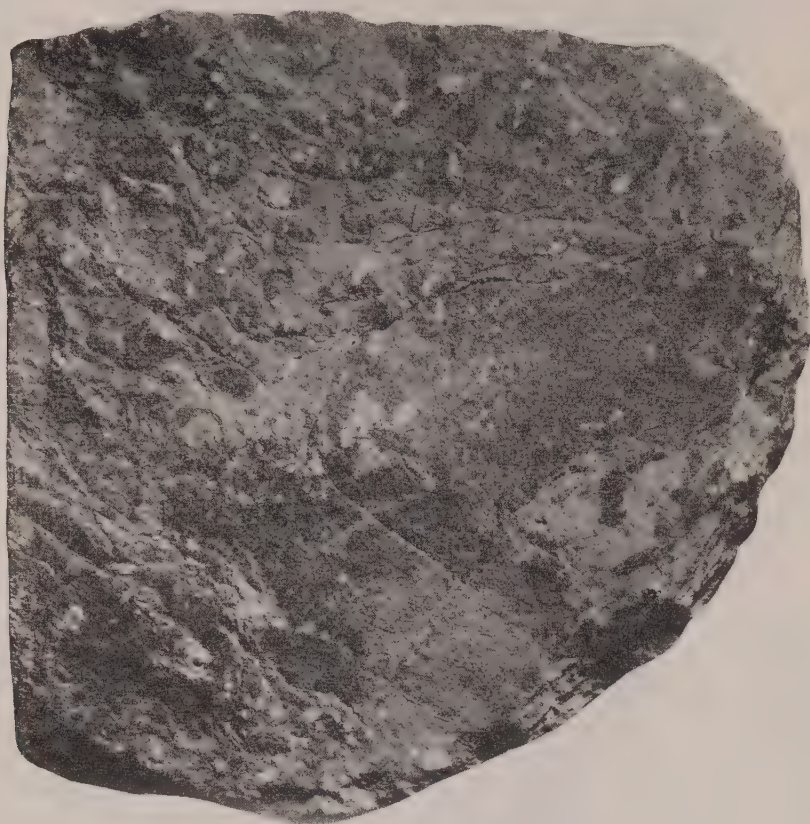
Figure 13. Coralline limestone with " *Pycnostylus* ",
slender and massive stromatoporoids.
Loc. The G₃ stage, Kuraoka, Gion-yama, Miyazaki
Prefecture. ×1. (Photo. by C. UEKI)

On the other hand, stromatoporoids play an importnt rôle for the reef-building in the Kawauchi series. Especially, its lower part is markedly charac-terized by the abundant occurrence of various stromatoporoids. Hence the name *Clathrodictyon*-limestone. Stromatoporoids in this limestone are, however, different from those of the G₃ limestones in the Outer Zone in their ecology. More pre-cisely, *Clathrodictyon*, *Actinostroma* and *Stromatopora* form somewhat massive colonies with distinct stromatoporoidal lumps the cross section of which show concentric structures. Besides, many slender forms such as *Clavidictyon* and *Amphipora* are abundant in the black limestones.

The mode of occurrence in the Kawauchi series indicates that these stroma-toporoids are not the true reef-builders and are ecological forms adapted for somewhat quiet waters of inter-reef facies. On the contrary, the stromatopo-roids of the G₃ limestone bear reef-building habit as above noted. These con-

trasts of the stromatoporoid ecology between the Southern Kitakami and the Kuma-Kii districts are undeniable evidence for the difference between the depositional circumstances of the two districts.

Judging from the available palaeoecological data, it can be concluded that the middle Wenlockian-Ludlovian limestones of Japan represent typical reefs of slightly rough water and very rough water facies. Those of the Kuma-Kii mountains were built under strong wave and current actions. Judging from the heavily massive limestones without arenaceous matter, and the remarkable linear distribution, they belong to a kind of barrier reefs on a linear swell on the oceanic side of the Chichibu geosyncline.

The reef limestones of the Kawauchi series, however, prodably were located in the back side of the basin where some terrigenous materials were supplied. The shale beds alternating with these limestones may indicate somewhat rhythmic change in depth. This change is presumably related to the repeated sinking of sea-floor after the deposition of limestone.

The limestones of the G_3 stage were, on the other hand, accumulated successively by continuous and gradual sinking of the sea floor. There was no interruption of reef building except for a short volcanic eruption, although several hidden hiati (HADDING, 1958) might be found in the limestones.

3. *The Takainari Series and the Stage G_4.*

The Takainari series in the southern Kitakami mountains is a relatively thin formation of green or reddish-purple colour containing radiolarians in siliceous slate. Coarse-grained sediments are absent in this series. The radiolarian rocks must be deep-water and off-shore sediments. Therefore the remarkable lithic change from the coralline Kawauchi limestones to the radiolarian-bearing rocks of Takainari seems to bear importance on the tectonic history.

Radiolarian remains are also often found in the green compact tuffs of the stage G_4 in the Kuma-Kii district. The G_4 stage is presumably long ranged from upper Ludlovian to middle Devonian. These tuffs are widely distributed throughout the thick series of this stage. It is an interesting fact that the stage G_4 is, as a whole, composed of coarse sediments including many intraformational conglomerate beds. In spite of this coarse rock facies, the intercalated tuffs are rich in radiolarian remains. These facts probably show the intermittent ash falls on fairly deep sea-floor where coarse sediments have been accumulating by more or less rapid subsidence of the bottom. The preponderance of silica supplied by the acidic volcanism may be an aid for radiolarians to flourish. No megafossil has been found in the G_4 stage. This fact together with the fairly continuous extension of radiolarian tuff beds in the coarse sediments vindicate the repeated ash falls on the floor of moderate depth. In other words, somewhat strong subsidence has taken place in the Kuma-Kii district of West Japan since the late Silurian period whilst the bottom oscillation and subsequent subsidence have been slight in Southern Kitakami, Northeast Japan. At that time the reef limestones have been formed in the Hida district. This difference in rock facies of the Chichibu geosyncline during the period from late Silurian to early Devonian may be attributed to a gentle crustal movement sympathetic with the

Kwangsi disturbance in South China.
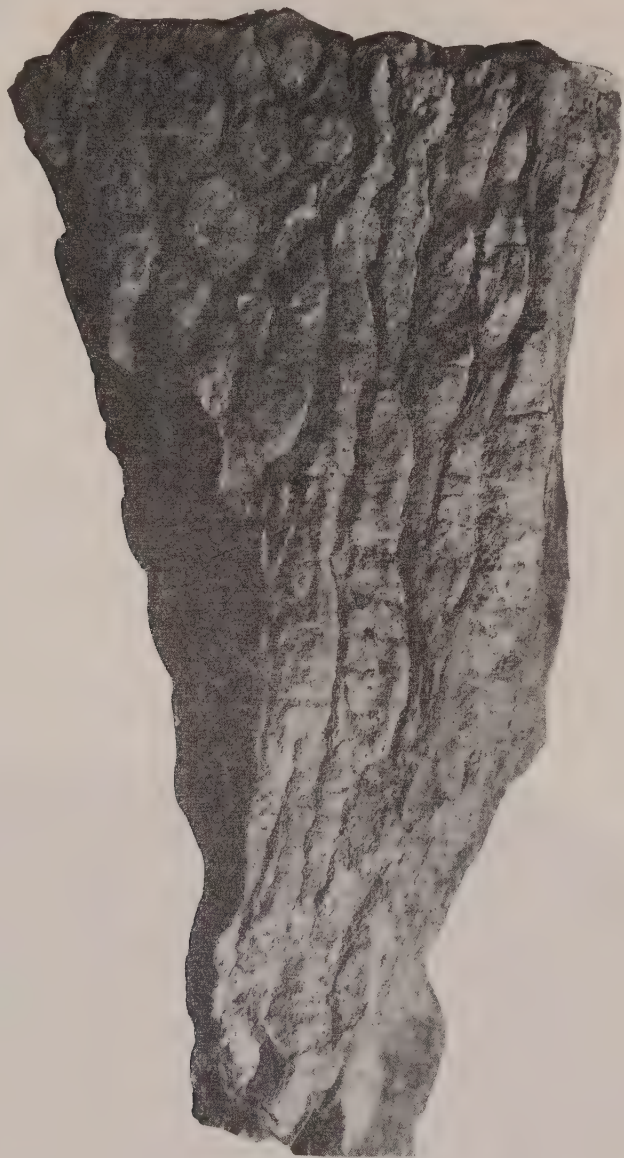
Figure 14. A part of the *Entelophyllum* hedge in the Fukuji
series showing closely packed cylindrical corallites.
×1. (Photo. by C. Ueki)

4. *The Ôno Series.*

This series is generally unfossiliferous. Only a few corals and stromatoporoids are reported from the lowest part where an impure limestone bed is intercalated. The ecology of this limestone is similar to that of the Kawauchi series. Remarkably enough, the coralline facies is no longer found in the Ôno series above this limestone. Most of the series is occupied by acidic ⊲olcanic materials
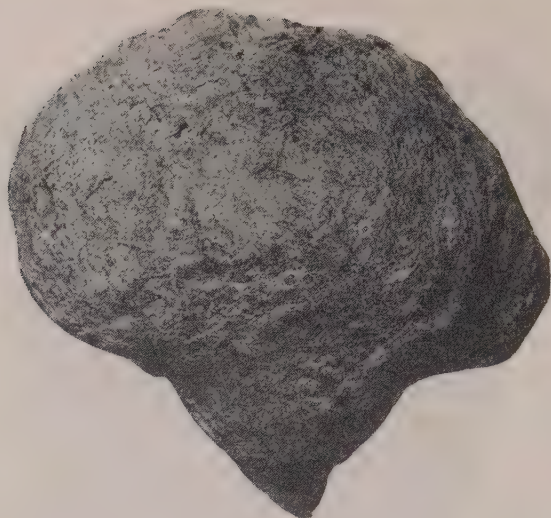
Figure 15. A globular *Favosites*-corallum which
is provided with a pointed base.

Loc. Takaharagawa series, Fukuji, Gifu Pref.
×1. (Photo. by C. Ueki)

Figure 16. A side view of the same specimen in figure 27 showing a
small basal part relative to the large corallum.
×ca 2/3. (Photo by C. Ueki)

and subordinate clastic sediments.

5. *The Fukuji and Takaharagawa Series.*

In the Hida district the Siluro-Devonian strata form a thick limestone series beside a small amount of clastic and volcanic rocks. The limestones are all highly fossiliferous, and especially rich in tabulate corals and stromatoporoids. Although a thorough faunal analysis is not yet accomplished, its favositid assemblage was reported by KAMEĬ (1955) and the writer (1959f).

These fossils occur in black or dark grey, often marly, massive limestones. Some are also found in the black shale beds intercalated in limestones. The most interesting occurrence is *Entelophyllum dilatoseptatum* in the marly bed 10 (zone F_2c) of the Fukuji series. The corallum of this coral is phaceloid, and the corallite length attains 25 cm or so. It was crowded with corallites almost vertical to the substratum in life time although now slightly inclined in the bed. This mode of occurrence coincides with LOWENSTAM's observation on the Illinois form. According to him, slender, occasionally branching coralla of this coral form dense hedges at place. "They aided reef building by functioning as sediment traps. In functional morphologic terms, slender corallites such as are found in *Entelophyllum* may be similarly a result of increased turbidity". The ecological condition must have been quiet water of inter-reef rather than rough water of reef platform.

The growth-forms of favositids in the Fukuji and Takaharagawa series are also interesting. The slender cylindrical or arborescent corallum of *Favosites hidensis* with small basal attachment suggests that the habitat was not in rough water, though the corallum-form itself depends not on the adaptation to quiet water but on phylogenetic modification of the Favositidae (HAMADA, 1959f).
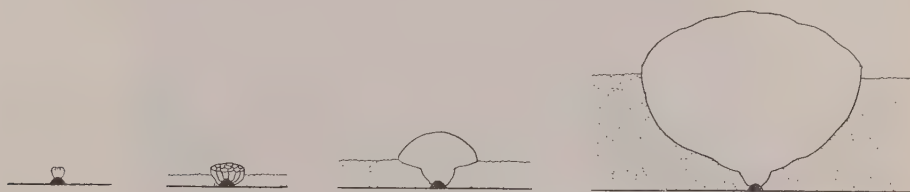
Figure 17. Growth of globular *Favosites* on muddy floor.

More significant is the small attachment of some massive favositid coralla which are coexistent with *F. hidensis*. A remarkable example is shown in fig. 15. Globular *Favosites* has been supported by a tiny corallum-base just like that of some solitary cup-shaped tetracorals. Another specimen of a large corallum has also a weak attachment (fig. 16). It seems impossible for such a large corallum to stand lonely on the muddy floor without any support but a small attachment. A possible explanation is that it was suspended by muddy substances as schematized in fig. 17. The corallum grew upwards with moderate lateral expansion as much as the mud floor rose up by sedimentation. If the presumption be correct, such a condition is expected only in quiet water of inter-reef or inner reef.

The stromatoporoids are also of the quiet-water forms. Namely, the stromatoporoid colony is expanded on the soft muddy floor forming definite lumps (figs. 18, 20). Some colonies are provided with nuclei of coral fragments such as favositids and cladoporoids. A remarkable example is in fig. 20. This specimen is obtained from a limestone which is an probable equivalence to a part of the Fukuji series, at Ôbora-dani, Ôtani, Izumi-mura, Ôno-gun, Fukui Prefecture. These nuclei are completely encrusted by stromatoporoid layers in various orientation. This fact indicates that the coexistence of these two animals is neither symbiosis nor struggle for existence. The coral fragments were helpful for anchoring of the stromatoporoid colony. It is probable that some of them were enclosed by the stromatoporoid colony by its rapid growth.

Figure 18. A polished section of a large stromatoporoid hump.
Loc. Takaharagawa series, Fukuji, Gifu Pref.
×1. (Photo. by C. UEKI)

An example for the symbiosis of a stromatoporoid with a coral was reported by OZAKI (1957). The slender cylindrical corallum of *Oborophyllum*, which is presumably an endemic genus of the Tryplasmatidae, is always surrounded by a stromatoporoid colony in cross section. In vertical section, the corallum is erect and supported by numerous fine hair-like epithecal projections which are

firmly enveloped themselves in the stromatoporoid layers.

Some slender stromatoporoids such as *Clavidictyon* and *Amphipora* are gregarious in some parts of the black limestones of Ôbora-dani and Oisé-dani of Fukui Prefecture. Extraordinarily well preserved colonies of these genera in the black calcareous mudstone of the Fukuji district are aligned almost parallel to the stratification as exemplified in fig. 21. This mode of occurrence is strongly suggestive of the back reef facies of quiet water condition.

The quiet water condition is also indicated by a black calcareous shale bed
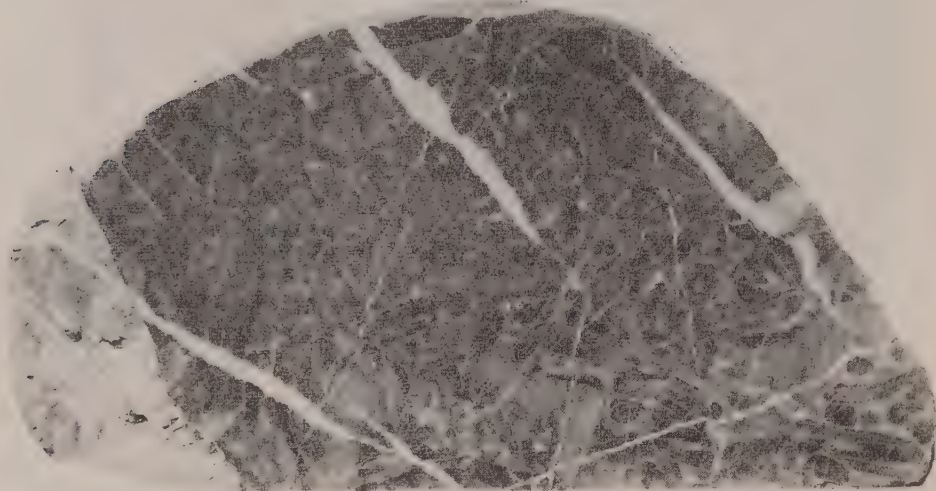
Figure 19. A polished section of limestone with slender stromatoporoid colonies. Loc. Ôbora-dani, Fukui Pref. ×1. (Photo. by C. UEKI)
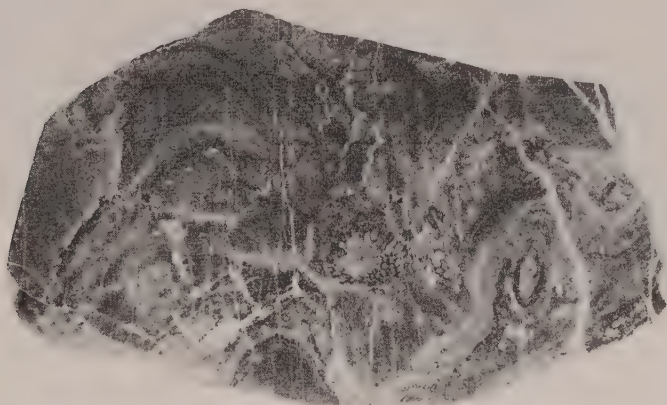
Figure 20. A polished section of a stromatoporoid colony with two humps. See the embedded coral fragments in the hump and depression.

Loc. Ôbora-dani, Fukui Pref. ×1. (Photo. by C. UEKI)
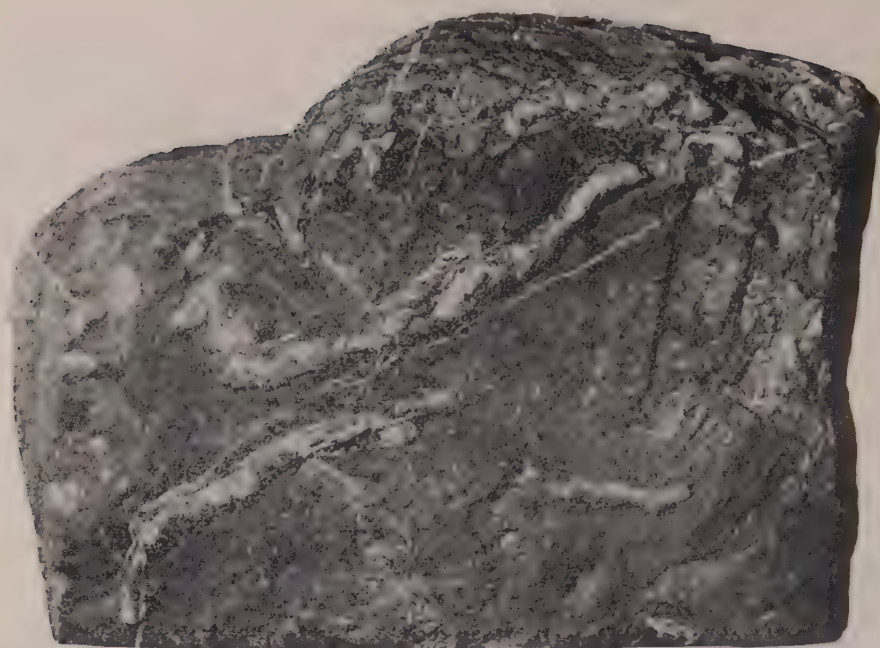
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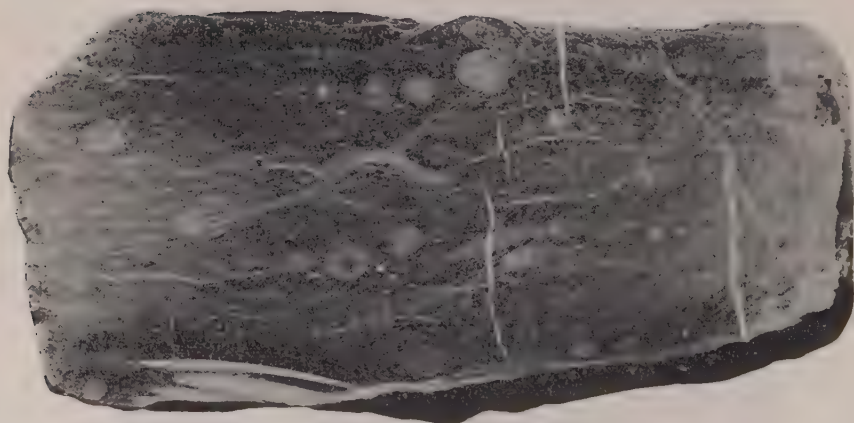
b

Figure 21. Cylindrical stromatoporoid colonies embedded in black marlstone,
showing the very quiet water condition of the reef site.

a: top view,   b: cross section

Loc. Fukuji series, Fukuji, Gifu Pref. . ×1. (Photo. by C. Ueki)

in the zone F_2b which contains many thin-shelled strophomenids and pelecypods (fig. 22). Corals are almost absent in this facies. Therefore it would be the most quiet water facies of the Fukuji reefs.

Figure 22. A slab of black shale with a strophomenid and *Atrypa*.
Loc. Fukuji series, Gifu Pref. ×1. (Photo. by C. UEKI)

The marly limestones with many delicately branching colonies of *Cladopora* were probably also deposited in the calcarenite facies of the back reef (fig. 23).

The Takaharagawa series is, however, composed of somewhat coarse materials. Coralla of *Favosites hidensis* are crowded in sandstone and sandy shale beds in association with trilobites and ostracods. An intercalation of impure limestone is highly fossiliferous and merges into coarse fragment limestone (figs. 24, 25). There are many corals, encrusting stromatoporoids, brachiopods, trilobites, and crinoids. These bio- and litho-facies are characteristic of the slightly rough water facies or the inner side of the reef platform.

Judging from these palaeoecological data, it can be said that the Fukuji and Takaharagawa series and their equivalents in the Hida district are, as a whole, composed of coralline reef limestones of slightly rough water facies with shaly rocks of quiet water facies. None indicates rough water. Therefore the depositional site of the Siluro-Devonian rocks in this district was presumably under the rather quiet condition free from the strong surf or shore current. This condition is somewhat similar to that of the Siluro-Devonian calcareous facies in the Southern Kitakami but quite different from that of the Kuma-Kii mountains of West Japan. The difference between the Hida and Kitakami districts is also in the abundance of brachiopods and gastropods in the limestones of the former.

Figure 23. Massive impure limestone with many slender *Cladopora* colonies.
Loc. Fukuji series, Gifu Prefecture. ×1. (Photo. by C. Ueki)

6. *The Nakazato Series.*

Most of the Ôno and the lower half of the Nakazato series are mainly com-posed of slate and keratophyre. The latter series becomes rich in sandstone and fossiliferous in the upper part. Its fauna includes many trilobites, brachio-pods and *Tentaculites*, but no corals. No remarkable limestone bed is present in this series. The fauna probably represents a neritic assemblage of shallow water condition.

7. *The Tobigamori and Ainosawa Series.*

The upper Devonian Tobigamori and Ainosawa series respectively in the Southern Kitakami and Sôma districts of Northeast Japan were deposited under a similar condition to that of the upper Nakazato series. Brachiopods are also predominant in their faunas. The only difference in the greater thickness of the sediment and occasional inclusions of some plant remains in the Tobigamori series. These plant fragments are not so well preserved and seem to be more or less waterworn. They are found in association with marine fossils such as *Cyrto-spirifer yabei*, *Camarotoechia pleurodon*, *Chonetes hardrensis* and *Aviculopecten* cf. *losseni*. These plants are drifts transported for a long distance by current water. This plant-bearing bed often shows reddish or purplish colour. However, un-doubted terrestrial sediments have not been found in the Japanese Middle

Figure 24. A slab of the fragment-limestone with crinoid stems and. *Thamnopora.*
Loc. Takaharagawa series, Fukuji, Gifu Prefecture.
× 3/4. (Photo. by C. UEKI)
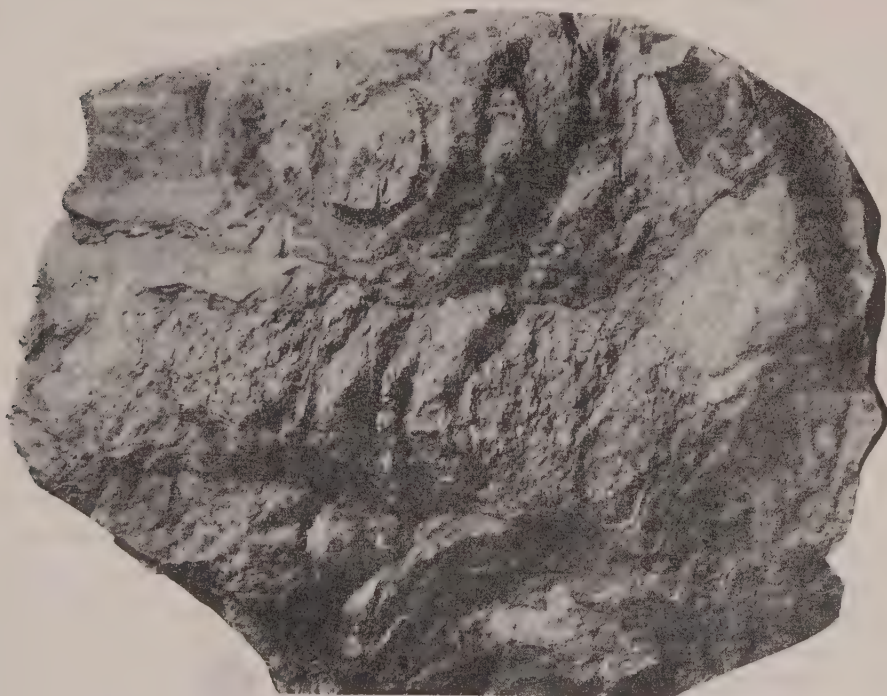
Figure 25. A slab of fragment-limestone with a cystiphylloid stock.
Loc. Takaharagawa series, Fukuji, Gifu Pref.
×3/4. (Photo. by C. UEKI)

Palaeozoic rocks.

The provenance of the plants is probably on the northwest side of the Chichibu geosyncline. Some metamorphic rocks in the conglomerate of the Tobigamori series (SUZUKI and MINATO, 1846) suggest the geology of the land in question.

8. *The Kiyomi Series.*

This series in the Hida district is also mainly composed of thick sandstones, and probably represents late Devonian age. The black thin limestone lenticles in the middle part contain massive *Favosites* and *Clathrodictyon*. As they are strongly deformed and recrystallized, any further faunal or ecological analysis cannot be made. An interesting fact is the presence of reddish conglomeratic strata with small granitic pebbles in the upper half of the series. Weak acidic igneous activity is recognizable in this series as a thin bed of rhyolitic tuff and tuffaceous breccia.

9. *Conclusive Remarks.*

Based upon the above analyses the ecological history of the Japanese Middle Palaeozoic rocks can be summarized in form of facies oscillation curves in fig. 26. In this diagram the biofacies is on the cross axis being arranged from the most stagnant water facies on the back side of the reef to the open sea floor from left to right respectively. This diagram is therefore not related with the grain-size of the sediments but with the ecology of fossils in these rocks.

The deepest and off-shore biotope is represented by radiolarian remains. The shelf facies is characterized by moderately thick-shelled brachiopods and trilobites such as *Cyrtospirifer*, *Dechenella* and *Thysanopeltella*. On the contrary, the typical reef facies of rough water condition is shown by the presence of thick-shelled *Conchidium* adjoining with several reef-building corals. *Encrinurus* occurs in profusion at the rather quiet water facies on the rear side of the reef flat. STUBBLEFIELD (1938) noted that the thick-shelled trilobites such as Asaphinae, Illaenidae and Encrinuridae are most frequently found in calcareous deposits, while the thin-shelled forms chiefly occur in argillaceous sediments as exemplified by the Agnostidae and Cryptolithida, etc. The black calcareous mudstone with thin-shelled strophomenids and delicate corals and stromatoporoids should be a sediment of the most quiet water condition. *Lingula* may be also a benthos in a similar circumstance.

As a matter of fact, further studies are earnestly expected in palaeoecology of the Japanese Siluro-Devonian biota. Though it is yet insufficient to conclude, it becomes more evident than before that the palaeoecological condition was different among the Hida and Southern Kitakami districts and the Outer Zone during the Siluro-Devonian period. This depends chiefly on the difference of the depositional site in the Chichibu geosyncline and partly on the influence of the Kwangsi disturbance. As the *Halysites*-bearing Silurian rocks are unknown in the Hida district, it is difficult to presume the geological events which have occurred in the Inner Zone of West Japan during the middle Silurian period.

As to the palaeoclimatological condition, it is judged from the extensive coralline reef limestones that the Japanese Siluro-Devonian was under tropical
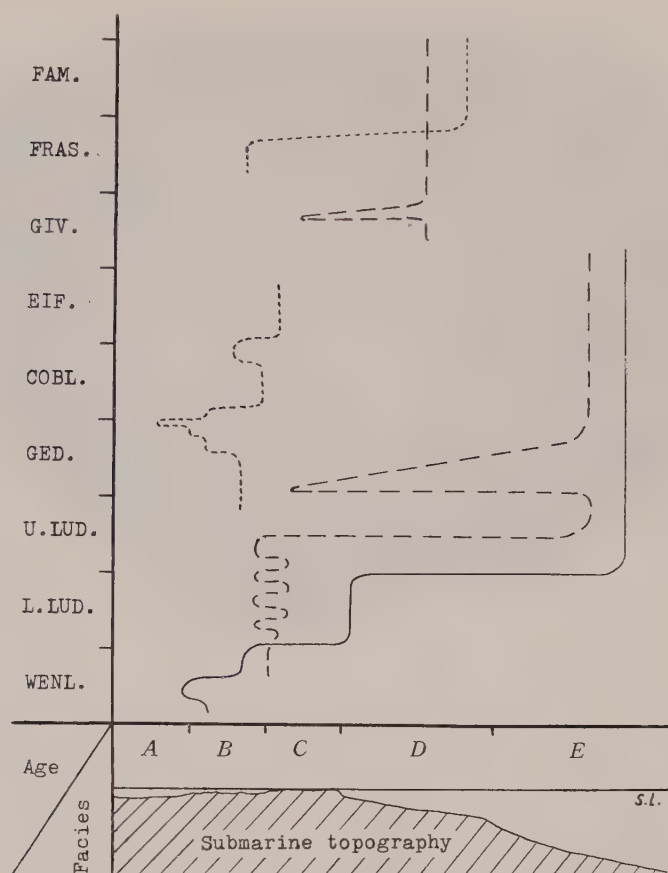
Figure 26. Facies change of the Middle Palaeozoics of Japan.

    Solid line: Kuma-Kii district, Outer Zone of West Japan.
    Broken line: Southern Kitakami, Northeast Japan.
    Dotted line: Hida district, Inner Zone of West Japan.
    A: Lagoonal facies (quiet water)
    B: Reef flat facies (slightly rough water)
    C: Marginal reef facies (rough water)
    D: Shelf facies (brachiopods and trilobites)
    E: Radiolarian facies (off-shore and moderately deep)

or warm climate. It can, however, hardly be overlooked that the favositid coralla of the lower-middle Devonian Takaharagawa series show a distinct periodical growth change as illustrated in fig. 27. This change is probably attributed to a certain climatic conversion such as annual or seasonal change. It is noteworthy that no growth change of this kind is perceptible on the specimens from the Silurian rocks of the Southern Kitakami and Kuma-Kii mountains.

    Of the halysitids the writer already pointed out that the seasonal change is not seen in the Japanese, Asiatic and Australian forms. Therefore the Asia-Australian Sea of the Silurian period must have been under the warm climate just like the present tropical sea (HAMADA, 1858).
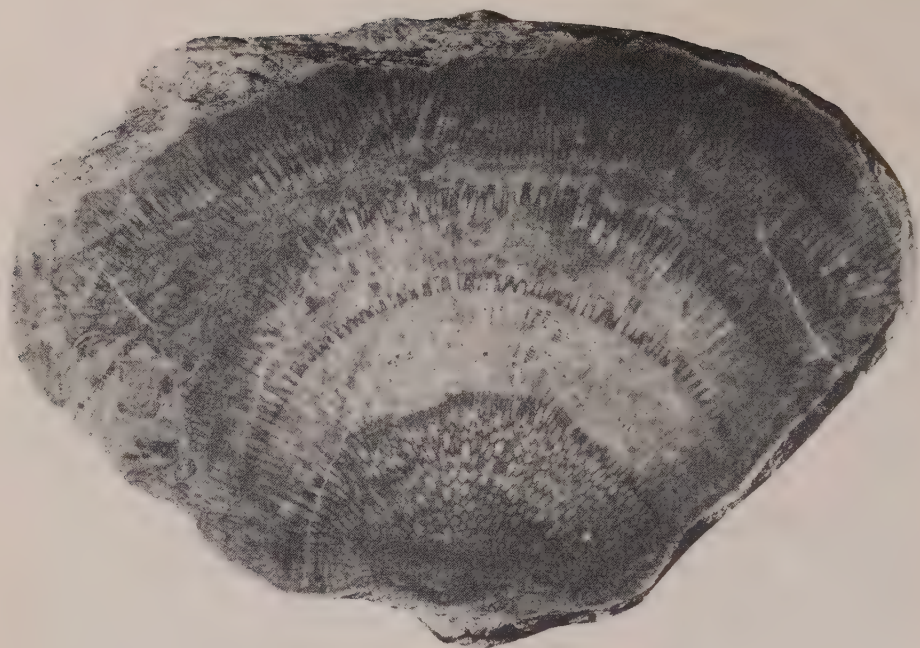
Figure 27. A Middle Devonian *Favosites*-corallum showing
the distinct periodical growth change.

Loc. Takaharagawa series, Fukuji, Gifu Pref.
× 2/3. (Photo. by C. Ueki)

Some important differences between the Silurian and Devonian climates will
be unvailed by more extensive studies on the Devonian corals of this province.

IX. Correlation of the Palaeozoic Group to
the Metamorphic Complexes

The sequence and lithology of the Middle Palaeozoic group of Japan are fairly
well known at present. Adjoining with the Upper Palaeozoic in Southern Kita-
kami their correlation is attempted in this chapter chiefly with the Sambagawa
crystalline schist complex of the Mesozoic Sakawa orogen in West Japan. The
Ryôké gneiss complex which is too much granitized is unsuitable for comparison.
Much remains as yet to be clarified of the Hida gneiss and Sangun crystalline
schist complexes which represent the metamorphosed axis of the Akiyoshi orogen.

1. *Fossils in the Sambagawa Schist Complex.*

The Sambagawa series (Kotô, 1888) has primarily been considered to be
Archaean chiefly because of its strong metamorphism (Naumann, 1885; Harada,
1890). Later, Yabe (1920) stated that these crystalline schists probably represent
the metamorphosed facies of the Lower Palaeozoic and older strata. They, how-
ever, regarded the schist complex as a stratigraphical unit older than the Upper
Palaeozoic Chichibu system. Ogawa (1929) contended that the complex had
been formed near the geosynclinal axis at the great depth and the Chichibu

system near the margin.*

The Sambagawa schist complex is generally in tectonic contact with the Chichibu system. The boundary is the Mikabu tectonic line (KOBAYASHI, 1935). At some places, however, the boundary is not so distinct or these two are said to merge from one to the other laterally. The Kôyasan area (TANAKA, 1950; HIRAYAMA and KAMBE, 1959), western Sizuoka Prefecture (TAKEDA et al., 1953), and northwestern Kantô district (SEKI, 1958) are such examples.

In 1938, FUJIMOTO discovered some radiolarians and foraminifers in the Sambagawa schists at the type locality, i.e., Kanaya in the Chichibu district, Central Japan. Namely, *Cenosphaera* 4 spp., *Cenellipsis* 2 spp., *Parodiscus* sp., *Rhopalustrum* sp., *Archicapsa* cf. *ficiformis* PARONA, *A.* sp., *Dicolocapsa* 2 spp., *Tricolocapsa* cf. *pilula* HINDE, *T.* sp., *Theocampe* sp., *Lithocampe* cf. *cretacea* RÜST, *Textularia* sp. were in small calcareous lenticles in the sericite schist. From this faunule he concluded that the Sambagawa complex represents the metamorphic facies of the Palaeozoic Chichibu system and also of the Mesozoic rocks (1939, 1952). According to him *Archicapsa* cf. *ficiformis*, *Tricolocapsa* cf. *pilula* and *Lithocampe* cf. *cretacea* all closely resemble the respective species from the Jurassic of Europe, Borneo and Japan.

With YAMADA, he (1948, 1949) found a crinoid limestone in the schists near Yorii-machi in the same district, and mentioned that the Sambagawa complex is decidedly not older than Ordovician and probably ranges in age from Carboniferous to Jurassic because the Crinoidea first appear in Ordovician and are rich in the Permo-Carboniferous rocks in the Chichibu system.

Prior to this, KOBAYASHI (1937) had pointed out that the Sambagawa metamorphics together with the Mikabu green rocks reveal the metamorphosed facies of the Chichibu group in the axial part of the Sakawa orogenic belt. Improbability of occurrence of the Jurassic radiolarian chert in the Sambagawa complex was sereously discussed by SUZUKI (1939) and KOBAYASHI (1941). SUZUKI emphasized that the non-metamorphic Lower-Middle Mesozoic strata in Japan are characteristic in the poverty of the volcanic materials in spite of the great thickness and persistence of the green schists in the Sambagawa complex which were considered to be originated from the effusives and pyroclastics.

KOBAYASHI disagreed with FUJIMOTO on the problem from tectonic viewpoint. Namely, the great lithic and faunal differences between the two upper Jurassic strata, i.e. the Tetori series of the Inner Zone and the Torinosu series of the Outer Zone of Southwest Japan must be attributed to the Eo-Nippon Cordillera (KOBAYASHI, 1935). The former series is composed of paralic basin deposits whereas the latter consists wholly of marine sediments with reef limestones. Therefore it is impossible to allocate the deep and off-shore facies with radiolarians between the outer and inner terrains of West Japan. He stressed that the occurrence of radiolarians in the Sambagawa schists means only the improbability of the Pre-Cambrian theory of the complex.

An additional occurrence of radiolarians in the Sambagawa complex was

* Fide postscript 5).

reported by MINATO (1956) from the Ôboké series, which is the lowest of the complex, near Boké, Tokushima Prefecture, Shikoku. Unfortunately the specimens were lost, but he mentioned that two kinds of Cyrtoids were recognized among them.

FUJIMOTO (1952) described another locality of radiolarians from dark red quartz-schist at Nakabuchi, Kôchi Prefecture near the preceding locality, but there is no Cyrtoidea, although deformation prevents their generic identification.

Through an intensive investigation on the radiolarian rocks KOBAYASHI and KIMURA (1944) concluded that the Sambagawa radiolarian fauna is somewhat allied to the Kamuikotan fauna by SUZUKI (1939) which is intermediary between the Carboniferous fauna and the Permo-Triassic Danau fauna of Borneo.

2. *Brief Summary of the Stratigraphy of the Sambagawa Schist Complex.*

As to the history of research since KOTÔ's study (1888), the reader is referred to the papers by MINATO (1952, 1958) and KOJIMA (1958). The petrography of the crystalline schists in Shikoku was greatly improved by SUZUKI (1930). Recent progress was made in the research in its mineral facies by SEKI (1958, etc.), MIYASHIRO and others (1958). An extensive survey of the complex have been carried on for long years for the purpose of the "Kieslager" mining. As a result stratigraphy of the schist complex is most advanced in Shikoku where the Kieslager is developed, as summarized by KOJIMA, HIDE and YOSHINO (1959) with special reference to the Kieslager and related volcanism. The stratigraphic succession was given by them as in table 2.

The major structure of the Sambagawa complex is simple in Shikoku as shown in the map (fig. 4). Its principal anticlinorium forms a sigmoid in Central Shikoku and the lower schist complex or the Koboké and older formations crop out along the axis.

Sandstone schist is predominant in the lower, and green schist in the middle part of the series. The Ôboké formation is especially a thick series of sandstone schist aside from some black schist and conglomerate schist layers. These rocks are coarse-grained enough to have been called "Ôboké gneiss" by OGAWA (1902). SUZUKI (1928, 1930), however, pointed out from mineral components, texture and chemical components that the so-called gneiss is a coarse-grained schist originated from acidic lavas and their tuffs. Prior to this, he recognized some thin layers of conglomerate schists containing many pebbles of acidic rocks of porphyritic texture.

In examining relic clastic minerals in the "Ôboké sandstone schist" including the Koboké, Kawaguchi and Ôboké formations, later KOJIMA and MITSUNO (1950) concluded that they had been probably derived from the underlying Nishi-iya group which includes the Kunimiyama granitic mass. Granite, granite-aplite, fine-grained biotite-quartz diorite, granite porphyry, quartz porphyry, quartz porphyrite, andesite, quartzite, sandstone, clayslate and basic igneous rocks were recognized among the pebbles of the conglomerate intercalations. Most predominant are granite and quartz porphyries, occupying more than 90 per cent. The largest pebbles attain 30 cm in diameter.

According to KOJIMA and MITSUNO (1950), the relic clastic minerals are

different between the northern and southern parts of the Yoshinogawa district separated by the Akano sheared zone (black paper schist zone). The northern area is characterized by common occurrence of augite in the Ôboké formation and the southern area by the presence of tourmaline in the Koboké formation.

Table 2. Stratigraphy of the Sambagawa metamorphic complex in Shikoku.
(After KOJIMA, HIDE & YOSHINO, 1956)

Formation	Lithic character	Thickness	Basic volc.
Ôjôin	Black schist with sandstone-, green- and quatrz schists	600+−1,080 m	non
Up. Minawa	Black-, green-, quartz-schists with sandstone schist	820–1,170	weak
Mid. Minawa	Mostly green-schist with quartz- and black schists	500–2,500	strong
L. Minawa	Black schist with sandstone-, green- and quartz schists	100–1,600	moderate
Koboké	Sandstone schists with green- and black schists	370–1,180	moderate
Kawaguchi	Black schist with green schist (stilpnomelane)	500–1,500	weak
Ôboké	Thick sandstone schist with black schist. Conglomerate schists in middle and upper.	1,300	non
Nishiiya	Mostly black schist with green- and quartz schist	1,130+	weak

According to KOJIMA (1949, etc.), though it is still debatable, the Koboké formation seem to lie unconformably on the Nishiiya group. The above mentioned various pebbles and relic clastic minerals in the Ôboké formation show that the Nishiiya group has been slightly folded before the sedimentation of the Ôboké and overlain by the Koboké formation. He named it "Minamihiura unconformity". Most of the relic minerals in the Ôboké and Koboké formations were probably derived from the Nishiiya group. Besides, a great amount of granitic pebbles and such minerals as quartz, orthoclase, microcline, acidic plagioclase, allanite, garnet and tourmaline is strongly suggestive of denudation of acidic igneous rocks. Therefore, a mylonitized granite porphyry at Kunimiyama in the northern area was presumed to be their provenance. Though the intrusive contact or stratigraphic relation of the granitic rock mass with other schists is unknown, the great similarities of this granite porphyry to the most abundant pebbles of the conglomerate compeled KOJIMA and his collaborator to this presumption. They stated, however, that the granitic rock is not a member of the basement on which the Sambagawa complex has accumulated but probably a product of the acidic igneous intrusion into the shallow zone of the earth crust which might be related to the pre-Ôboké gentle folding. At Minamihiura, the Koboké equivalence is seemed to overlie the Nishiiya group with unconformity, where the Kawaguchi and Ôboké formations are absent. In the northern

area, the Koboké is also presumed to cover the Kawaguchi with partial discon-
formity (Kojima, 1950). The Nishiiya group disagrees with the Kawaguchi in
that eight green schist layers are intercalated in the former, whilst the latter
bears only four in the almost same thickness. Besides, the characteristic in the
latter is stilpnomelane-quartz (-calcite) schist instead of piedmontite-bearing
hematite-quartz schist which is well developed in the former (Kojima, 1958).
The Nishiiya group or the like is unknown in other schist area. Therefore the
Nishiiya must be the lowest of the Sambagawa complex instead of the correla-
tive of the Kawaguchi formation. The lithic difference between the two are
too great to be attributed to facies change because it is believed that lithic
facies is fairly monotonous and extensive in the Sambagawa complex.

3. *Correlation of the Sambagawa in Shikoku to the other Schist Complex.*

The prodominance of green schists in the main part of the Minawa forma-
tion and of sandstone schists in the strata underlying the Koboké is a remark-
able characteristic of the Sambagawa complex in Shikoku. Keeping this fact
in mind, an attempt is made for its comparison with several other schist com-
plex. According to Kojima (1958), the schists at the Saganoséki peninsula,
Kyûshû are mainly composed of the Minawa and partly of the Koboké forma-
tion. The Sambagawa complex in the Kii peninsula is younger than the lower
Minawa. The crystalline schists at the Tenryû district represent the whole
Minawa (Nakayama, 1953). Further to the northeast, Sambagawa complex at
the type locality is equivalent to the Minawa, while the schists with stilpno-
melane-quartz schist at the Nogami-Misawa area belong to the Kawaguchi-
Koboké formations.

The writer (1959g) noted that the acidic Akazawa formation at Hitachi, the
Matsugadaira schists in the Sôma and Motai schists in the Southern Kitakami
district are all similar in original lithology to the lower Sambagawa, especially
in the intercalated acidic rocks.

Of the metamorphic rocks of the Inner Zone, Matsumoto (1958) clarified
that the Tsukushi metamorphic complex in Kyûsuhû, which is probably a part
of the so-called Sangun metamorphic complex, strikingly resembles the Samba-
gawa in Shikoku in lithic aspect. It is probably comparable to the Sambagawa
higher than the Kawaguchi formation.

According to Mitsuno (1959), the Sangun complex in Okayama Prefecture
attains more than 2,000 meters in thickness and divisible into the black schist-
rich lower half and the upper mainly composed of green schists with acidic
schists at the top and sandstone schist at the base. The acidic schists, which
were first discovered by Kojima and Mitsuno (1953), are originarily quartz
porphyry, rhyolite, rhyolitic clastics, quartz diorite, grano-diorite and micro-
granite. The former three are all of hypabyssal nature. A conglomerate schist
with pebbles of quartz diorite, granite and andsite which attain 15 cm or so
was newly reported. Its matrix is said to be green schists or metamorphosed
tuffaceous matters. Another layer of schistose conglomerate exists in the black
phyllite of the same area in which andesite pebbles are predominant (Mitsuno,
1959). These acidic and sandstone schists are extensive and serve as keys to

the upper part of the complex. From these lithic characteristics the writer suggested the possible correlation of these metamorphics to the lower Sambagawa complex (1959g). Furthermore, it is an important fact that the metamorphic rocks gradually transmit upwards into non-metamorphosed Palaeozoic at the Bessho and southeastern Yanahara areas of this district.

"Kieslager" is sometimes associated with the above acidic schists. In the Sambagawa complex they occur mostly in the Koboké formation. Another instance for an intimate relation of the "Kieslager" to the similar acidic schists is seen at the Hitachi mine where ore bodies are enclosed in the schistose acidic Akazawa formation which is overlain by the non-metamorphosed and fossiliferous lower Carboniferous Ayukawa formation.

Of the Sangun metamorphic rocks in Yamaguchi Prefecture, KOJIMA (1953) presumed that the Tsuno group represents an equivalence to the Kawaguchi-Minawa formations and the overlying non-metamorphic Ôta group corresponds to the Ôjôin formation at the top of the Sambagawa complex.

4. *Provisional Chronology of the Sambagawa Schist Complex.*

In 1950, KOBAYASHI claimed a tentative chronology of the Sambagawa complex. The Ôboké and Besshi series were presumed Ordovician-Devonian because the predominance of green schists in the latter series which was thought comparable with the Devonian volcanism. Recent studies, however, clarified that the basic volcanism was violent during early Carboniferous, while the Devonian volcanism was acidic (MINATO et al., 1959). Incidentally, KOBAYASHI's Ôboké and Besshi series were in OGAWA's sense mostly higher than the Koboké formation and the rest in the recent concept respectively. Furthermore, he had placed the Mikabu green rocks and the Kumé series to the Silurian-Carboniferous formations.

In Shikoku the Mikabu green rocks occupy the southern margin of the Sambagawa schist complex but separated from the Sambagawa proper by black phyllonite of the Kiyomizu tectonic zone (KOJIMA, 1958). To avoid confusion KOJIMA (1958) denominated Southern Sambagawa complex for the so-called Mikabu system because the term has been often used in various ways.

Several fossils have been discovered from the so-called Mikabu system (YAMASHITA, 1896; WATANABE, 1921; ÔTANI, 1926; MATSUMOTO and HETSUGI, 1949). However, these fossiliferous rocks have been excluded from the "Mikabu system" whenever fossils were found. In the current opinion the system is not an independent stratigraphical unit as SUZUKI (1938) once considered but represents a marginal part of the Sambagawa complex which is characterized by low metamorphism and intrusion of basic and ultrabasic rocks. KOJIMA (1950) regarded the "Mikabu system" to represent a zone of intense ultrabasic intrusions along a dislocation belt. This Southern Sambagawa is as a whole thought to merge gradually southwards into the less or non-metamorphosed Chichibu Palaeozoic rocks. Therefore, in some places the Mikabu tectonic line becomes obscure. The Kumé series probably belongs to this transition.

An almost complete Middle—Upper Palaeozoic succession of the Chichibu geosyncline is only obtainable in the Southern Kitakami district. The Palaeozoic

volcanic activity was recently summarized by Minato and others (1959a–c). The Sambagawa sequence is described only from Central Shikoku by Kojima and others (1956). Therefore, one cannot help but using them for comparison of the metamorphic and non-metamorphic region. The metamorphosed Sambagawa belt was considered to belong to the Para-Kitakami facies in its original lithology on one hand, while the Southern Kitakami Palaeozoic represents the Kitakami facies on the other. Both of them are characterized by abundance of basic volcanic rocks and their derivatives (Kobayashi, 1941). The former facies differs from the latter in the lack of limestone. In this respect, the Kumé series and the so-called Mikabu system or the Southern Sambagawa complex with limestone lenses are rather akin to the Kitakami facies proper. The stratigraphy of these formations is, however, obscure.

Minato and others (1959b, c) summarized the Upper Palaeozoic sequence in the Southern Kitakami as in table 3.

Table 3.   The Upper Palaeozoic Group in Southern Kitakami.
(After Minato et al., 1959b, c)

Age		Series	Whole thick.	Thick. Basic v. r.
Permian	Late	Toyoma	1, 800 m+	0
Permian	Middle	Kanokura	1, 200 m	0
Permian	Early	Sakamoto	1, 300 m	50 m
Carboniferous	Late	Nagaiwa	710 m	60 m
Carboniferous	Middle	Onimaru	300 m	0 m
Carboniferous	Early	Ôhira	1, 115 m	335 m
Carboniferous	Early	Arusu	715 m	270 m
Carboniferous	Early	Hikoroichi	780 m	371 m

The predominance of acidic volcanic material and coarse clastics in the lower-middle Devonian and upper Devonian strata respectively is characteristic. Combined with granitic clastics of the G_4 stage in West Japan, these acidic and psammitic natures of the Devonian strata agree with the lower Sambagawa complex or the Ôboké, Kawaguchi and Koboké formations.

On the contrary, in the Southern Kitakami Palaeozoics basic volcanic rocks are richest in the lower Carboniferous. The similar volcanism is found also in the Hitachi area of Southern Abukuma (Fujimoto, 1924), Taishaku area of Chûgoku (Yokoyama, 1959) and so on. The prevalence of the basic volcanics in the lower Carboniferous throughout the Chichibu geosyncline bears a great importance because such an activity is expectable also in the metamorphosed terrains.

As above mentioned, green schists, which were originated chiefly from the basic volcanic materials, are predominant in the main Minawa formation (table 2), but in other formations subordinate in volume. Thus the correlation of the non-metamorphosed lower Carboniferous to the main part of the Minawa for-

mation is fairly justifiable.

Paying attention to the thickness and lithology of the Southern Kitakami sequence, an accumulation curve is drawn as graph A in fig. 28. The same treatment is also applied to the Sambagawa schists (fig. 29). It is interesting to find a similarity between the two graphs. Assuming the acidic and basic volcanism respectively in early Devonian and early Carboniferous periods in the metamorphics, the accumulation curve of the Sambagawa schists can be adjusted as the graph B in fig. 28.
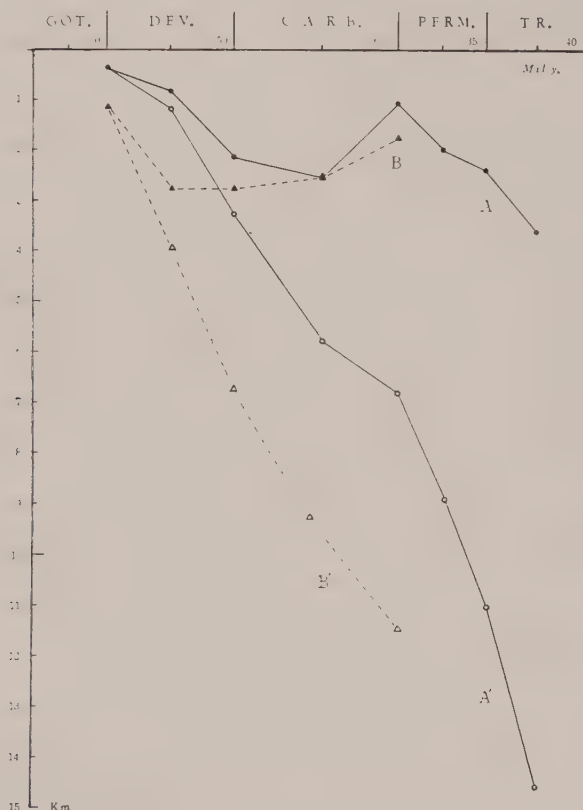
Figure 28. Thickness of the Palaeozoic group of the Chichibu geosyncline.
Graph A showing the thickness of the non-metamorphosed Palaeozoic group in Southern Kitakami. A′: integrate thickness.
Graph B showing the thickness of the Sambagawa schists. B′: integrate thickness.

As a result, the Ôjôin formation or the top · division of the Sambagawa complex, which was once thought to include the upper Permian rocks (KOJIMA, 1953), is presumably late Carboniferous. This presumption makes one easy to understand the fact that the total thickness of the schists complex (max. 11,460 m) is lesser than that of the non-metamorphosed Palaeozoic rocks (max. 14,500 m+). It is probable that the pre-Permian sediments have been deposited in the Sambagawa terrain along the axis of the Chichibu geosyncline 4,500 m thicker

than in the Southern Kitakami district on the margin of the geosyncline.
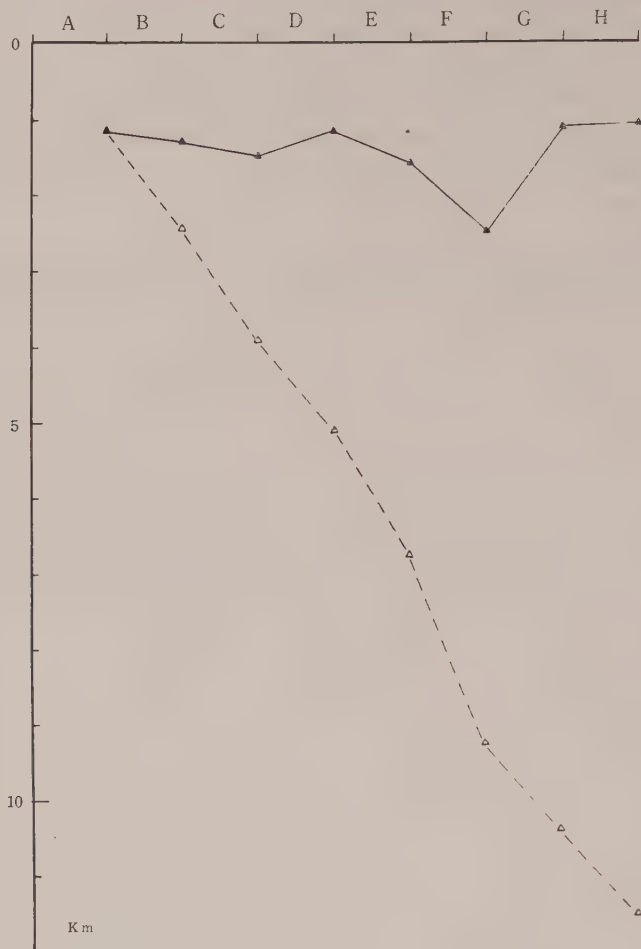
Figure 29. Thickness of the Sambagawa crystalline schists in Shikoku.
A : Nishiiya group   E : Lower Minawa formation
B : Ôboké formation   F : Middle Minawa formation
C : Kawaguchi formation   G : Upper Minawa formation
D : Koboké formation   H : Ôjôin formation
Broken line showing an integrate thickness.

The chronology of the Sambagawa complex in Shikoku is tentatively determined as in table 4 with reference to the volcanism.

The Devonian age of the lower Sambagawa formation is supported by the radiolarian assemblage in which the Cyrtoidea are absent (Fujimoto, 1952) or rare (Minato, 1950). It is generally accepted that the Sphaeroidea are prodominate but the Cyrtoidea almost absent in the Silurian rocks (Kobayashi and Kimura, 1944). With regard to the radiolarian remains in metamorphic rocks, the selective preservation of fossils requires a more careful analysis (Ichikawa, 1946). However, the presence of the Cyrtoidea, though they are rather small

in number, in the Ôboké formation suggests that the formation is Devonian instead of Silurian or older. This agrees with the tentative chronology based upon the volcanism.

Table 4. Tentative chronology of the Sambagawa schist complex.

	Late	Ôjôin formation
Carbon.	Middle	Upper Minawa formation
	Early	Middle Minawa formation
		Lower Minawa formation
Devonian	Late	Koboké formation
	Middle	Kawaguchi formation
	Early	Ôboké formation
Silurian (?)		Nishiiya group

5. *The Hida Gneiss Complex.*

The pilo-magmatic axial belt of the Akiyoshi orogen is represented by the Hida gneiss complex inclusive of the Oki gneiss. It is mainly composed of gneissose granite with augen-gneiss, amphibolite and lime-silicate gneiss. Although its stratigraphy is obscure, it is well known that the lime-silicate gneiss and crystalline limestone accompanied by amphibolite are predominant in the central and western parts of the Hida gneiss region. They are considered to have been originated from limestone and basic volcanic rocks. The crystalline limestone is accompanied by some workable graphite deposits. In the eastern part staurolite schist is found in association with limestone and amphibolite. From the relic phenocrysts of plagioclase and corroded quartz Ishioka and Suwa (1956) concluded that the Unazuki staurolite schist has been generated from rhyolite. This schist is intercalated in limestone and amphibolite. As already mentioned, the lower Devonian in the Hida district is mainly composed of a thick limestone with thin rhyolite beds. Therefore, it can be said that the non-metamorphosed Devonian is quite similar to the presumed original rocks of a part of the Hida metamorphic complex.

Recently Kobayashi (1959) pointed out that the Hida gneiss is possibly composed of the Middle Palaeozoics. He (1941) has suggested further that the gneisses are the metamorphosed facies of the Akiyoshi suite of which thick limestone is characteristic. These suggestions are now well endorsed by the discovery of the staurolite schist which can be considered lower Devonian. The most prevalent lime-silicate gneiss and amphibolite are comparable to the limestone and the associated "schalstein" of the Akiyoshi and Para-Akiyoshi suites from lower Carboniferous to Permian in the non-metamorphosed terrain. The characteristic of the former suite is the development of limestones which range from lower Carboniferous to Permian as exemplified by the Akiyoshi, Taishaku, Fukuji and Ômi limestones. Clastic sediments are subordinate in this suite. On this account, the Hida gneiss quite agrees with the Akiyoshi suite.

Incidentally, the Hashidate crystalline schists at the northern extremity of

the Hida mountains are mainly composed of green schists of glaucophanitic mineral assemblage and associated with pelitic schists (Banno, 1958). These schists are considered to belong to the Sangun schist complex which lies on the outer side of the Hida gneiss and represents the mio-magmatic zone of the Akiyoshi axis. The complex was probably derived from the Para-Akiyoshi suite in which pelitic rocks and "schalstein" are predominant. It possibly includes the lowest Carboniferous formation containing a large amount of the basic volcanics.

X. The Siluro-Devonian Crustal Movement in the Chichibu Geosyncline

1. *Facies Variation of the Siluro-Devonian Formations.*

Several characteristics are recognized in ecology of the Silurian and Devonian reefs of the Chichibu geosyncline. The difference exists also in other lithic facies. The G_4 stage in the Kuma-Kii district at the Siluro-Devonian transition is not only so tuffaceous as the Ôno and lower Nakazato series in in Southern Kitakami but also so coarse as to intercalate many conglomerate layers. In coarseness the G_4 stage agrees with sandstone of the lower Sambagawa series. Although there is a small amount of rounded pebbles in the lower and middle Devonian formations of Southern Kitakami, most sediments are rather fine-grained and contain many shaly layers.

Most important fact is the sudden disappearence of limestone at the end of the early Ludlovian age in the Outer Zone. The G_3 reef limestones are, therefore, all in the *Schedohalysites kitakamiensis* zone. No calcareous rock is found in the G_4 stage. The ceasing of reef-building was probably related to the strong volcanic activity and also to the supply of coarse clastic materials by which the sea floor was probably subsided. Namely, a strong volcanic eruption and subsidence have taken place at latest Silurian or early Devonian and the thick series of coarse sediments were accumulated in the Sambagawa as well as in the Chichibu terrain. Radiolarians in them show rather deep and off-shore facies in spite of the coarse clastics. No megafossil of shelf and reef habitat with calcareous shell is as yet found in the G_4 stage.

A similar history is read in the Siluro-Devonian formations of the Kitakami district, although the sediments are finer and a thin reef limestone exists in the lower Devonian. The sudden change which interrupted limestone-building is shown by the facies change from the calcareous upper Kawauchi series to the Takainari radiolarian slates. A coralline limestone on the Takainari indicates a short interval at the beginning of the Devonian which was suitable for reef building. Then the circumstance became again unfavourable for sedimentation of carbonates. This was caused by the strong volcanic activity and subsidence of the basin. Tuffs contain many radiolarians but no calcareous shells.

In Southern Kitakami, the volcanism almost ceased by the early Coblenzian. Later sediments are sandy and brachiopods and trilobites are common in them. The fauna probably suggests a shallow continental shelf for their habitat. Thin-bedded limestones were occasionally found at places.

The above facts combined with ecological analysis enable the writer to obtain oscillation curves in fig. 25 which show the facies changes during the Siluro-Devonian period in the Kuma-Kii and Southern Kitakami district.

Of the Silurian formation in Hida, the available data are still too meager to analyze its facies. But the Devonian is well represented by thick limestones and their ecology is elucidated. Most remarkable is the quiet or slightly rough water condition of the reef site probably from latest Silurian to middle Devonian, though the Coblenzian sediments are somewhat coarse and less calcareous. Intercalations of acidic volcanic rocks in the lower Devonian limestone are thin and fine-grained. The Unazuki schist derived from limestone and rhyolite are probably equivalent to the Fukuji series. They are strikingly different in lithology from their equivalents of the Southern Kitakami and the Kuma-Kii mountains as analyzed in fig. 25.

This difference between the Inner and Outer Zones depends partly upon the difference in the strength of the volcanism and partly upon the crustal movement. In other words, at the Siluro-Devonian transition the sea floor of the Outer Zone was abruptly sunk as far as the depth which does not allow reef-building, while in Hida reef-buildung was continued. A change in the depth of the sea bottom, which took place in Southern Kitakami, was similar to that of the Outer Zone but probably not so remarkable.

This subsidence was simultaneous with the Kwangsi disturbance in China, and was accompanied by the strong acidic volcanism in Japan.

The upper Devonian Tobigamori and its equivalents are characterized by conglomerate-bearing psammitic rocks with some red beds, and yield land plants such as *Leptophloeum* and *Cyclostigma*. They are characteristic plants near the margins of the area in the Chinese Heterogen which suffered from the Kwangsi disturbance. They occur further in the upper Devonian in Eastern Australia where the latest Silurian Bowing and late middle Devonian Tabberabberan movements have taken place. Thus, these plants are all found in sandy clastics of the mobile belts after the crustal movement. On this account, the Japanese Tobigomori florule is strongly suggestive of a land behind the Chichibu geosyncline which probably belongs to the Chinese Heterogen. Some pebbles of metamorphic and plutonic rocks in the lower and upper Devonian might be supplied from the land in question. It is also possible that this land is a provenance of the archaegranite in the Permo-Carboniferous conglomerate of Japan.

2. *Tectonic Bearings of the Sambagawa Sequence.*

The lower Yoshinogawa series can be correlated to the Devonian from lithology. The lowest Ôboké formation is especially well marked by the coarse sediments and conglomerate layers. The rock composition is said to be mainly made of porphyritic granitoid. If the correlation be correct, this coarse clastics are coeval with the G_4 stage in the Chichibu terrain in Shikoku and Kyûshû.

According to KOJIMA and others, there are two sedimentary provinces concerning the lower Yoshinogawa series which overlies the Nishiiya series with clino-unconformity. There may be some controversy as to the so-called Minamihiura clino-unconformity in the southern area. But it is undeniable that the lower

Yoshinogawa is quite rich in coarse clastics.   Suzuki and others noted that acidic
volcanics such as quartz-keratophyre are among them.   Chemical composition
of the "Ôboké sandstone schist" agrees with that of Daly's rhyolite and obvi-
ously different from greywacke sandstone.   Therefore the composition of the
"Ôboké sandstone schist" closely resembles that of the G_4 stage.

   This similarity bears crucial importance for analysis of the Siluro-Devonian
crustal movement.   The thick and coarse series of the lower Yoshinogawa pro-
bably shows unstability during the Middle Palaeozoic period.   If so, the Minami-
hiura clino-unconformity and a partial discordance between the Koboké and
Kawaguchi formations by Kojima and sedimentary provinces by Kojima and
Mitsuno may be veritable.
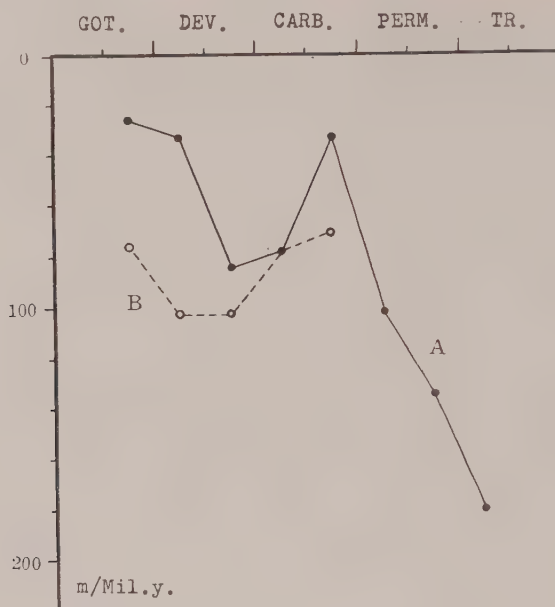
Figure 30.   Rate of Accumulation of the Japanese Palaeozoics.
Solid line: Non-metamorphosed Palaeozoic and Lowest
Mesozoic formations in the Southern Kitakami district.
Broken line: Sambagawa crystalline schists.

   At any rate, the unstability of the basement is indicated by the Middle
Palaeozoic thick coarse sediments not only in the non-metamorphosed terrain
but also in the metamorphosed Sambagawa terrain.   The rapid accumulation of
the upper Devonian rocks in the Sambagawa and Chichibu terrains is also well
shown in fig. 30, though it does not represent the true synorogenic sedimenta-
tion.   Slight disconformities and some conglomerates in the Siluro-Devonian of
Southern Kitakami may also represent the unstability of the basement but it
was not so mobile as in the Kuma-Kii district of West Japan.

   In conclusion, the Middle Palaeozoic history in Japan is summarized as fol-
lows:

   In the middle and early late Silurian periods the Chichibu terrains of the

Outer Zone and Southern Kitakami were tranquil where thick reef limestones were deposited on the marginal portions of the Chichibu geosyncline. At the close of the Silurian the Outer Zone was first suffered from a sympathetic movement with the Kwangsi disturbance. As a result a thick series of coarse sediments with a huge amount of acidic volcanic materials was accumulated in the Sambagawa and Chichibu terrains. The same movement and volcanism took place in Southern Kitakami slightly later. It was, however, not so violent. In the Hida district the quiet condition was probably still maintained, seeing that the Silurian (?) -Devonian reef limestones are thick and volcanic intercalations are thin. At about the Givetian age the volcanism and subsidence were ceased, and the area was on a shallow shelf during the period from late middle to late Devonian. By the gradual subsidence of the geosyncline or probably the uplift of the hinter land, however, thick and coarse sediments were deposited and land plants imbedded during the following period. This condition was probably prevalent throughout the Chichibu geosyncline in late Devonian time.

XI. Basement Problem of the Chichibu Geosyncline

At the beginning of geological research in Japan, all metamorphic complexes have been presumed Pre-Cambrian basement rocks. It became evident, however, that they represent the axes of the Triassic Akiyoshi and Cretaceous Sakawa orogens (KOBAYASHI, 1941). None has been detected of the basement of the Chichibu geosyncline.

· The oldest fossiliferous rocks in Japan are Wenlockian in age. KOBAYASHI (1948) once suggested that, as one of possibilities, the oldest strata in the Chichibu geosyncline are probably Ordovician, assuming that the development of the Heinan, Yokusen and Chichibu geosynclines from the Korean Peninsula to the festoon islands of Japan was successive.

As above mentioned, the Nishiiya or the lowest Sambagawa series is a pre-Koboké formation, which is presumed upper Devonian, and possibly a pre-Ôboké formation, which is thought as the lower Devonian or uppermost Silurian. Predominance of siliceous rocks and black schists in the Nishiiya group is strongly suggestive of the off-shore facies of the sediments.

In the Kwangsi orogenic zone of South China, the pre-Devonian sediments are chiefly represented by fine argillaceous rocks as already pointed out by KOBAYASHI (1951). The Siluro-Devonian strata of Japan reveal a sympathetic movement with the Kwangsi disturbance. From the comparative tectonics it is probable that the Nishiiya group is the oldest in the Chichibu geosyncline and Ordovician or early Silurian in age. The underlying strata are unexposed.

In 1952, FUJIMOTO, KANUMA and MIDORIKAWA reported that the Silurian Naradani group in the Hida district unconformably overlies the Mugishima gneiss, which was considered by them to be a member of the Hida gneiss complex, with a remarkable conglomerate at the base. They concluded, therefore, that the Hida gneiss does not represent a metamorphic axis of the Akiyoshi orogen but the basement of the Chichibu geosyncline and probably Pre-Cambrian.

Through the survey of the area, however, the writer arrived at the conclusion that the Mugishima " gneiss " is actually a granite intruded into the " Silurian strata " producing gneissosity near the periphery, and that it is akin to Funazu granite (HAMADA, 1955). FUJIMOTO (1959) and INAMORI (1959) emphasized the lithic similarity of the granite pebbles of the conglomerate to the Mugishima gneiss. But the similarity does not mean sedimentary origin of the conglomerate. Most " pebbles " should be igneous blocks of a pseudo-conglomerate which are the product of the intrusion of the Mugishima granite into a sheared belt (HAMADA, 1955 ; NOZAWA, 1959). By these reasons the Pre-Cambrian theory for the Hida gneiss complex must be abandoned.

It is, however, an important fact that there is a true conglomerate bed which is also mylonitized into a pseudo-conglomerate with the intruded Mugishima granite blocks. This conglomerate was once presumed to be Permian by the present writer (1955) on account of the tuffaceous and arkosic nature as often met within the lower Permian Ichinotani conglomerate in the Fukuji area of this district. But, there is no evidence of Permian age. It seems an intraformational conglomerate comparable with the upper Devonian Natsuyama conglomerate of the Southern Kitakami district. Noteworthy is the red shaly matrix of a part of this bed like that of the Natsuyama conglomerate.

In 1954, TOMITA published a paper entitled " Geologic Significance of the Color of Granite Zircon, and the Discovery of the Pre-Cambrian in Japan ". According to him, the purple and rose-pink zircons are predominant in the Archaean rocks of the world and the following granitic rocks in Japan containing such accessory zircons are presumed to be Younger Archaean.

    The Hida gneiss complex and its equivalents
        Unazuki granite
        Unazuki augen-gneiss
        Unazuki banded gneiss
        Amô granodiorite
        Mugishima granite
        Dôgo granite
        Oki augen-gneiss
    Kuma-Kii district, Outer Zone of Southwest Japan
        Yatsushiro gneiss
        Nabaé gneiss
    Northeast Japan
        Ôhira granite

The Oki granite-gneiss and paragneiss are Older Archaean. Among them the Mugishima granite was proved to be a younger intrusive along the Median Tectonic Line of the Inner Zone. From the tectonic point of view, the Hida and Oki gneiss complex area are considered a plio-magmatic belt of the metamorphosed axis of the Akiyoshi orogen (KOBAYASHI, 1941). The Pre-Cambrian theory by means of the zircon colour is no more than a conjecture until it is endorsed by the absolute age determined by isotope method.*

The above listed gneisses of the Outer Zone are exposed as small masses

* Fide postscript 4).

with · close relation to the Yokokura igneous rocks. It is noteworthy that the Yokokura rocks are always heterogeneous and partly provided with distinct gneissosity just like the marginal part of the Funazu and Hikami granites in the Hida and Southern Kitakami districts respectively. Most important is that the "Younger Archaean" granites above listed are closely related to the tectonic line along which granite was intruded. The Unazuki gneisses and Amô grano-diorite are all located at the sheared belts in the gneiss region. According to Nozawa (1959), the Amô granite is closely connected with genesis of the Hida gneiss.

Incidentally, the Hikami, Arusu and Ôno granites in the Southern Kitakami are said to have dark reddish brown to lilac-brown accessory zircons.

According to Minato and Suzuki (Minato, 1946 ; Suzuki and Minato, 1946), the Natsuyama conglomerate of the upper Devonian Tobigamori series contains many metamorphic and igneous rocks. Subsequently Ôkubo (1950) noted an occurrence of a few granitic pebbles in the lower Devonian Ôno series (bed 5). With regard to the latter occurrence, Sendô (in Hanzawa, 1954) is of opinion that the pebbles were transported not by water current but by volcanicity as xenolithic fragments. At any rate, these metamorphic and igneous rocks are quite exotic for the Japanese Middle Palaeozoic strata, and considered to be derived from an unknown land which situated to the northwest of the Chichibu geosyncline or from the deep-seated substrata beneath the Silurian rocks. A similar occurrence of the pebbles is also reported from the so-called Murakami conglomerate (Minato, 1949) in the Hida district.

The origin of the granite pebbles in the Usuginu and other Permo-Carboni-ferous conglomerates is also a matter of dispute. The pre-Permian plutonism has as yet been uncovered in Japan except for the probable pre-Devonian Kunimi-yama granite in Shikoku. These exotic granite pebbles were once called archae-granite by Kobayashi (1941). Watanabe and Kanô (1954) suggested that some of these granitic rocks were derived from the Hikami granite on account of ' the lithic similarity · between them. But Kobayashi stated its improbability saying that the Hikami granite can not be the provenance of these pebbles because the "Usuginu-type" conglomerate is not restricted to the Kitakami mountains but widely distributed all over the Chichibu geosyncline, and because the granite mass is too small to supply the vast of these pebbles (1951, 1956). Kanô (1956) and Minato (1958) considered that the Hikami-type includes the Hikami, Yamagami, Funazu and Mitaki (Yokokura) granites. Minato (1958) presumed, therefore, that these pebbles could be derived from the Ryôké granite zone, which he thought as a metamorphosed zone of the Palaeozoic orogen. But there was no Palaeozoic orogeny in the Chichibu geosyncline, if some prorogenic movements are excluded. The Ryôké granitic zone is a plio-magmatic belt of the Cretaceous Sakawa orogenic axis. Incidentally, the absolute age obtained by chemical analysis of the lead isotope in fergusonite in a granite pegmatite from Ehimé Prefecture, Shikoku, which belongs to the Ryôké zone, was referred by Minato as 230×10^3 years. But it is a misprint for 216×10^3 years (Takubo et al., 1953, p. 50).

KOBAYASHI suggested the greater importance of the pre-Moscovian granite in South China where is in the western wing of the Chichibu geosyncline, and also a significance of the Kunimiyama granite which is thought pre-Devonian.

YAMASHITA and others (1952) considered the "Mitaki igneous rocks" are pre-Permian, and further presumed that the granitic pebbles in the upper Permian Yasuba conglomerate and its equivalents were derived from these igneous rocks. The Mitaki or the Yokokura igneous rocks are, however, obviously post-Triassic in age (HAMADA, 1959g).

As reviewed briefly, no basement of the Chichibu geosyncline has yet been found out. The archaegranite problem still remains unsolved. A sympathetic crustal movement with Kwangsi disturbance probably accompanied by the Kunimiyama granitic intrusion in Japan is, however, somewhat suggestive of the *Heimat* of the pebbles (KOBAYASHI, 1951). But as mentioned by KOJIMA and MITSUNO (1950), the Kunimiyama granitic rock could not be a basement of the geosyncline judging from its hypabyssal rock nature.

Another way of approach to the solution of this problem is a research on the metamorphic rocks in the structurally disturbed zones and xenolithes in the associated granitoids.

The Térano metamorphic rocks (ICHIKAWA et al., 1956) are distributed in the Kuroségawa Structural Zone in the Kuma-Kii district of West Japan. They are mainly composed of garnet amphibolite, biotite schist and gneisses. The metamorphic grade is said to be an epidote-amphibolite facies (=almandine garnet zone) (ICHIKAWA et al., 1956). There is no comparable metamorphics in the Outer Zone. The Sambagawa metamorphic complex belongs as a whole to the chlorite zone except for the northern part where are biotite, common hornblende, diopside and kyanite present, and is a kind of epidote-amphibolite facies. The grade of metamorphism declines southwards in the Sambagawa belt (MIYASHIRO, 1959). Therefore, the Térano metamorphic rocks and their equivalents, for example the Yatsushiro gneiss in Kyûshû, Miyagadani metamorphics in Tokushima Pref., Shikoku and Nabaé gneiss in the western Kii peninsula, and so on, are quite exotic for the terrain. Some authors presumed that they represent the basement of the Chichibu geosyncline which was squeezed out along the tectonically disturbed zone.

HAYAMA (1959) noted an occurrence of gneissose garnet-amphibolite among the metamorphic rocks. According to him, the garnet in the rock is a typical eclogite-garnet with 10 per cent of MgO content. This kind of garnet is characteristic in Pre-Cambrian gabbros and charnockitic rocks. Therefore he concluded that the garnet-bearing rock had been originated from certain rocks similar to them by retrogressive metamorphism when it was brought up with the Yokokura igneous rocks to the present site along the Kuroségawa zone.

Some metamorphic rocks also occur along the tectonic belts of the Inner Zone. In the Hida district they form small masses separated from the Palaeozoic rocks by faults or serpentinite intrusions. The metamorphic rocks at Réngé (NOZAWA, 1959), Yarigadaké (SHIBATA and KIMURA, 1959), Konabé-dani (SHIBATA and HARA, 1954), Tochio (Gamata crystalline schists by KAMEI, 1950), Matsudani

Mazégawa crystalline schists by Kanuma, 1952=Matsudani crystalline schists by Fujimoto et al., 1953), Isé (Ishioka and Kamei, 1950) may be such examples. They are mainly composed of biotite schist, garnet-bearing mica schist, actinolite schist, amphibolite, amphibole gneiss and biotite gneiss. These rocks have once been thought Pre-Cambrian by Ishioka and Kamei (1950) and others, but there is no stratigraphic evidence. On the contrary, Nozawa (1959) noted that they are the tectonites which were originated from the Palaeozoic rocks.

It is uncertain whether or not they represent the equivalents to the Hashidaté crystalline schists, which is characterized by glaucophanitic metamorphism (Banno, 1958) and considered to belong to the Sangun metamorphic schist complex of the Akiyoshi orogenic axis, or whether they represent some other metamorphosed products by later plutonism or local tectonic movements.

The second example in the Inner Zone is the Kômori metamorphic rocks in the Maizuru zone which is also a tectonic zone characterized by the Yakuno sheared intrusives. Biotite gneiss, biotite-hornblende banded gneiss and amphibolite are main constituents of the metamorphic rocks. They look similar to the Térano metamorphics (Kanô et al., 1959). Therefore the Maizuru zone is compared to the Kuroségawa Structural Zone and also to the Median Tectonic Line of Inner Zone, notwithstanding the fact that there is no definite Middle Palaeozoic rock. However, the meta-rhyolite reported by Yamashita (1957) from this zone may be Devonian in age.

The Tsubosawa gneisses in the Hikami granite mass of the Southern Kitakami mountains (Suzuki, 1952) is probably similar to the above mentioned metamorphics.

The metamorphic rocks in these tectonically disturbed zones are as a rule characterized by the mineral assemblage of epidote-amphobolites facies of rather high temperature, which is different from the Sambagawa schists, although they are now mylonitized and retrogressively metamorphosed in various grades by later thermal effect. In the present knowledge, no comparable type of metamorphism is detectable among the regionally metamorphosed rocks in Japan. Derivation of these rocks by contact metamorphism of granite intrusion seems to be impossible, judging from the mineral facies and the closely related granitoids which are mylonitic and devoid of strong thermal effect to the wall rocks. Only a possible explanation is that they were produced by these granitoids at the great depth and thereafter transported to the present level by the crustal movements, unless they represent a piece of the basement rocks of the Chichibu geosyncline.

XII. Conclusions

Salient results crystallized out from the above descriptions and discussions are as follows:

1) The fossiliferous Middle Palaeozoic group of Japan are usually distributed in certain intensely disturbed zones of non-metamorphic terrains in frequent companion with sheared granitoid sand exotic metamorphic rocks. These zones

are genetically related to the Mesozoic structural basins.

2) The Middle Palaeozoic of the Kuma-Kii mountains in West Japan is divisible into four, i.e. $G_1 \sim G_4$ stages, by lithology and palaeontology, which range from lower-middle Wenlockian to middle (?) Devonian.

3) The intensive rhyolitic eruption in the Kuma-Kii district during the Siluro-Devonian period is comparable to those in the Hida and Southern Kitakami districts. It is recognizable also in the metamorphic complexes of the Sakawa and Akiyoshi orogenic axes.

4) The Siluro-Devonian facies variations were probably caused by a gentle crustal movement sympathetic with the Kwangsi disturbance of South China. The clastic rocks of granitic composition are characteristic of the Siluro-Devonian transition of the Kuma-Kii district, and of their metamorphosed equivalents in the lower Sambagawa schist complex.

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Postscript :

1) KAWATA described that the Hayashinohira formation at Naradani is composed of sandstone, clayslate and limestone with a fairly large amount of acidic tuff. However, the writer could recognize only a few thin beds of rhyolitic tuff and tuff-breccias in this formation. KAWATA, K. (1960) : Additional of Geology near Naradani, Gifu Prefecture (Japanese). *Earth Sci., No. 49,* p. 39 ; Plutonic and Volcanic Rocks exposed in Neighbourhood of Naradani, Gifu Prefecture (Japanese). *Jour. Geol. Soc. Japvn, Vol. 66, No. 778,* pp. 476–477. HAMADA, T. (1955, MS) : Geological Study of the So-called Mugishima Gneisses and their Surrondings (Japanese with English Abstract). *Graduation Thethis at the Yokohama National University, 1955.*

2) *Dania tsuzuraensis* was recently described by NODA with illustrations. NODA, M. (1960): A Gotlandian Coral newly found in the Hôei Mine, Ôita Prefecture, Japan. *Sci. Rep. Tohoku Univ., Ser. 2 (Geol.), Spec. Volume, No. 4* (HANZAWA *Mem. Volume*), pp. 125–126, Pl. 13.

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4) Ar^{40}/K^{40} dating of five biotite samples from the gneisses of the Hida metamorphic complex gives an average age of 180 million years. KUNO, H., BAADSGAARD, H., GOLDICH, S. and SHIOBARA, K. (1960): Potassium-Argon Dating of the Hida Metamorphic Complex, Japan. *Japan. Jour. Geol. Geogr., Vol. 31, Nos. 2–4,* pp. 273–278.

(Nov. 26, 1960)

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(Nov. 31, 1960)

MOLLUSCAN FAUNA OF THE PLIOCENE SANNOHE GROUP OF NORTHEAST HONSHU, JAPAN

II. The Faunule of the Togawa Formation

By

Kiyotaka CHINZEI

With Four Plates

Abstract

The molluscan faunule in the Togawa formation of the uppermost horizon of the Pliocene Sannohe group is described. Pelecypods are dominant in specific and individual numbers. The Recent forms contained in the faunule indicate that the faunule as a whole may be close to the coastal water assemblage of northern temperate region of the west Pacific. Six fossil communities can be recognized on the basis of species composition in connection with lithologic facies of the enclosing rocks. Paleoecology of these communities is also discussed.

The faunule has the characters of the Tatunokuti fauna of the Pacific side of Japan, along with some elements of the Omma-Manganji fauna of the Japan Sea side. Chief differences between the Tatunokuti and the Omma-Manganji faunas may be explained by the difference of bathymetrical situation of the habitat of these faunas. The faunule contains also some species which has been considered to be restricted to the Miocene deposits of the Japanese Islands. These species may be considered the relicts of the Miocene fauna. This is explained by the tectonic history of the area.

Contents

§1. Introduction

The present paper is the second report on the molluscan fauna of the Pliocene Sannohe group distributed in the Mabechi River valley, in the northern margin of the Kitakami mountains, Northeast Honshu, Japan. The report presents the first detailed discussion on the molluscan faunule of the Togawa formation, the uppermost constituent of the Sannohe group. Little has hitherto been known about the faunule except for the occurrence of *Fortipecten kenyoshiensis* (CHINZEI, 1960) with some other pelecypods.

To furnish the fundamental data for the molluscan paleoecology, the writer describes the mode of fossil occurrence together with the facies of the enclosing rocks, and describes the fossil communities recognized by the particular species or combination of species. The horizontal and vertical distributions of these communities are also discussed in relation to paleogeography restored on the basis of the stratigraphical and other geological data.

As previously stated (CHINZEI, 1959), the fauna of the Sannohe group contains the faunal elements of the Pliocene deposits of the Japan Sea side of Northeast Japan, although the fauna occurs in the Pacific coast. The Kubo faunule (CHINZEI, 1959) in the middle horizon of the Sannohe group is characterized by predominance of the Omma-Manganjian type elements which is said to represent the Pliocene fauna of the Japan Sea side. The Togawa faunule, on the other hand, is the peculiar admixture of the Tatunokuti fauna of the Pacific coast and the Omma-Manganji fauna. In this paper, the writer intends to explain some aspects of faunal relation between these faunas distributed in Northeast Japan.

He prefers to conclude that they may be explained as the coastal and the oceanic water assemblages in the same sea rather than to regard them as geographically isolated two faunas.

Acknowledgements:
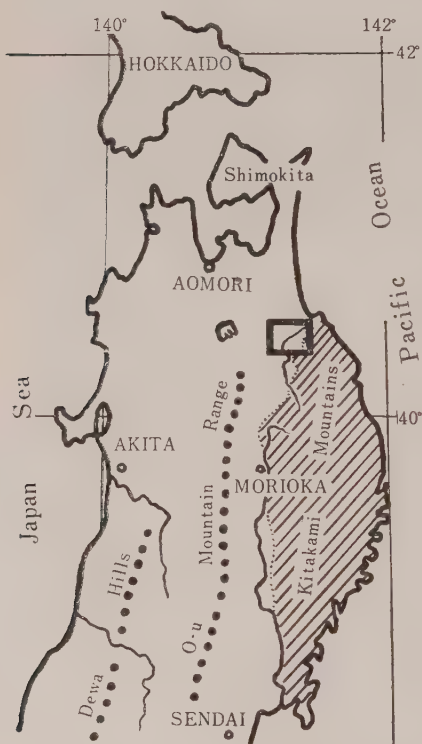
Text-fig. 1. Location of the studied area (hatched area: older sedimentary and plutonic rocks of the Kitakami Mountains).

§ 2. Geology and Mode of Fossil Occurrence

Geological situation of the fossil localities

The Sannohe group is the Pliocene deposits distributed between the northern Kitakami mountains and Ôu mountain range. It forms a large horse-shoe-shaped basin structure which opens to the north. The group consists mainly of marine siltstone and sandstone, about 1,100 m in maximum thickness, and shows a single large cycle of sedimentation. It can be divided by lithology into the following four formations in descending order (see also fig. 2 of Chinzei, 1959):

1. Togawa formation: thick sandstone and siltstone in the west; frequent alternation of mudstone, sandstone, conglomerate and tuff in the east. 150–300 m thick.
2. Kubo formation: tuffaceous sandstone; a pumice tuff bed in the middle, and the molluscan faunule (Kubo faunule) reported by the writer (1959) in the lower part. 150–300 m.
3. Shitazaki formation: gray siltstone. 150 m.
4. Tomesaki formation: lithofacies varies remarkably, shell-limestone in the lower part; sandy facies predominates in the eastern area, muddy facies in the western area. 100–250 m.

The molluscan fossils under consideration are contained in the Togawa formation which is the uppermost formation of the group and is overlain unconformably by the Pleistocene Kamikita group of marine terrace deposits. The geological age of the formation is considered to be upper Pliocene. The main body of the formation is barren of fossils. Fossils occur limitedly in the eastern part of the distributed area of the formation.

In the environs of the fossil localities, there is found an anticline of flexuous structure which is called the Tatsunokuchi flexure, running from south to north and gently plunging to the north. The eastern limb is the down-thrown side of the flexure, and its dip ranges from 60° to vertical along the axis.

The anticline divides the Togawa formation into two parts, eastern and western limbs. The rock facies is different in both sides. In the eastern side, the formation may be subdivided into lower and upper parts. The lower part is characterized by remarkable changes in rock facies both laterally and vertically. Whereas the lithology is less variable in the upper part of the eastern side and the main part of the western side.

The lower part of the eastern side is composed mainly of irregular alternation of mudstone, tuffaceous or non-tuffaceous sandstones and pumice tuff. Lenticular conglomerates are frequently intercalated. The majority of the molluscan fossils is contained in this part. The upper part of the eastern side consists of massive sandstone with thin intercalations of siltstone and tuff. In

the western side, the rock facies is rather uniform over wide area. The lower
part is composed of gray massive siltstone, and the main part is represented by
medium- to fine-grained sandstone intercalated with some pumice tuff layers.
The detailed lithology of the formation is shown in the columnar sections (fig. 2).
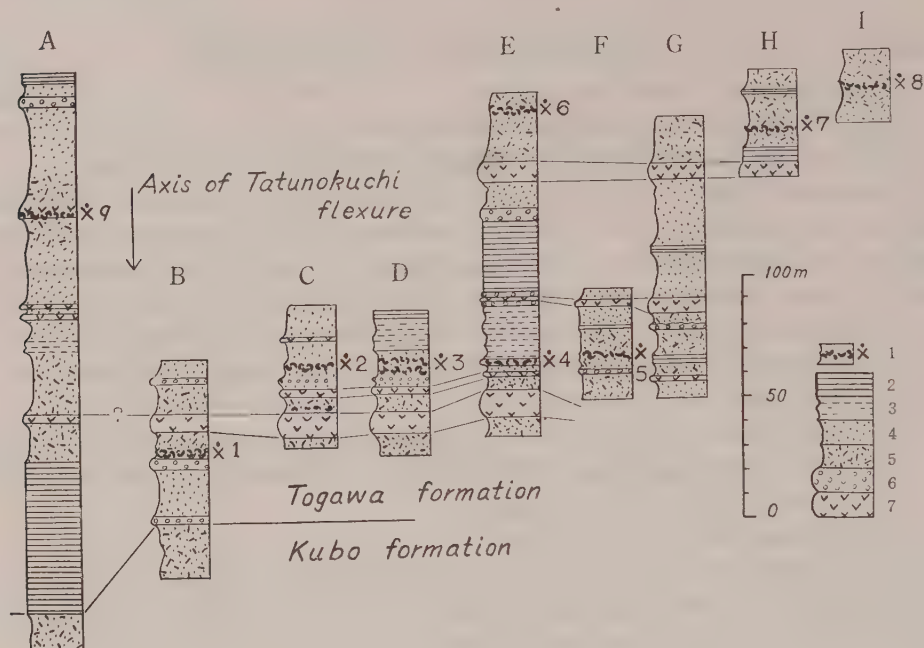
Text-fig. 2.   Columnar sections of the Togawa formation.

1: fossil occurrence;   2: siltstone;   3: alternation of siltstone and sandstone;
4: non-tuffaceous sandstone;   5: tuffaceous sandstone;   6: conglomerate;   7;
pumice tuff. A: West of Dogamae (western limb of the Tatsunokuchi flexuous
anticline) ; B: Amai, Nanbu-machi ; C: southwest of Torado, Nagawa-machi ;
D: west of Torado; E: west of Ken'yoshi; F: southeast of Kitamuki, Gonohe-
machi; G: Toga, Nagawa-machi; H: NNW of Tomabechi, Chibiki-mura; I:
east of Mutsu-Ichikawa station.

The fossil localities of the Togawa formation studied here are nine in num-
ber. Most of them, excepting Loc. 9, are found in the eastern side of the
flexuous anticline.   They can be divided into two horizons, about 100 m apart
vertically from each other. Locality Nos. 1 to 5 are in the lower horizon which
is situated in the lower part of the formation, and Loc. 6 to 8 belong to the
upper horizon included in the upper part. Loc. 9 is located in the western side
of the anticline apart from the other localities; however, it can be correlated
with the upper horizon of the eastern side.

The difference of lithology between both sides of the anticline may be
explained by an influence of the movement of the anticline, which had been
initiated in the middle horizon of the Sannohe group and continued to the pre-
sent time (CHINZEI, 1958). It is likely that the anticline existed as a rise during
the deposition of the Togawa formation. Even the temporary emergence of the
eastern limb of the anticline may be expected in the early period of the deposi-

tion of the formation judging from the development of thick pisolite-tuff towards the eastern limb. In addition, the formation of the eastern side, especially in its lower part along the limb, exhibits a remarkable change in rock facies. This may indicate that the area along the anticline was closer to the shore or shallower than the area on farther east.

The rock facies of the Togawa formation grades into nonmarine sandstone and siltstone in the southern extension of the studied area. While the southeastern region of the area is occupied by the upper Miocene volcanic rocks and the Paleozoic formations, and no evidence of deposition of the Togawa formation was available.

On the basis of these conclusions and some other geologic data, a paleogeographic map of the area can be drawn as shown by fig. 3. Although the disposed line of localities of the lower horizon from Loc. 1 to Loc. 4 is oblique to the restored coastline, the disposition may represent the order from near-shore to offshore. A similar relation is recognized in the upper horizon, from Loc. 6 to Loc. 8.
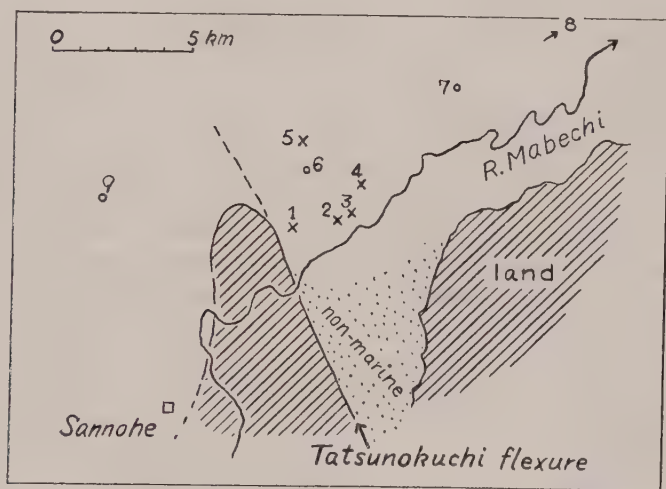
Text-fig. 3. Paleogeographic map of the area.
×····the lower horizon, ○····the upper horizon.

Mode of fossil occurrence

The fossils are found exclusively in tuffaceous sandstone or in some places conglomeratic sandstone. Most of them occur in clusters in certain parts of the sandstone beds, and are seldom found with solitary specimens in other major parts of the sandstone.

The mode of occurrence of the fossils in nine localities is explained as crowded fossil-bed, or in other words, they are assembled in particular zones parallel to the stratification. The thickness of these zones varies from 0.3 m to about 2 m. Within a zone, a few especially crowded layers and relatively scanty parts can be observed generally.

Vertical or horizontal changes of the constituent species in one locality

were not recognized except for the cases of *Anadara tatunokutiensis nagawensis* of Loc. 3 and *Pecten kenyoshiensis* of Loc. 4. *Anadara nagawensis* gathers exclusively in the lowest part of the fossil zone of Loc. 3, and the main constituents of the assemblage are found in the upper part about 1 m from the *A. nagawensis* layer. In Loc. 4, *Pecten kenyoshiensis* is relatively rich in the upper part of the conglomerate, while others are more abundant in the lower part.

The majority of the pelecypods are found as odd valves except for some specimens of *Mercenaria stimpsoni*, *Panope* cf. *estrellana*, *Mya japonica oonogai* etc. Water erosion or destruction of shells is not remarkable on pelecypods. Gastropods are rare both in species and individuals, and most of them are fragmental and water-worn specimens.

The majority of the fossils have lost their original calcium-carbonate. Most of them have been replaced by montmorillonite. Others were found as moulds and casts. The original shell-materials are preserved only in a few cases, i. e., all specimens from Loc. 4, and *Pecten sannohensis* and *Polytropa shiwa* from Loc.
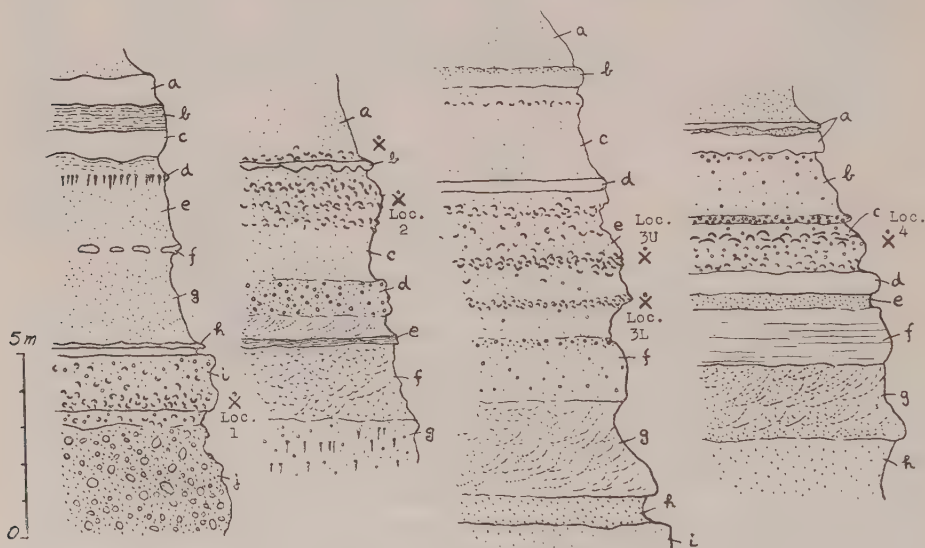
Text-fig. 4. Sketches of the outcrops in the lower horizon.

Loc. 1. a: white fine tuff, b: laminated pumice tuff, c: pink fine tuff, d: silt tube, e: fine tuffaceous sandstone, f: siltstone, g: fine sandstone, h: sandy siltstone, i: fossil-bearing conglomeratic coarse sandstone, j: pebble to cobble conglomerate.

Loc. 2. a: fine tuffaceous sandstone, b: siltstone, c: fine pumiceous sandstone, d: granule to pebble conglomerate, e: laminated siltstone, f: very coarse pumiceous sandstone, g: conglomeratic coarse sandstone.

Loc. 3. a: medium massive sandstone, b: pumice tuff, c: medium massive sandstone, d: fine tuff, e: fossil-bearing medium sandstone, f: conglomeratic very coarse sandstone, g: cross-laminated coarse pumice tuff, h: medium pumiceous sandstone, i: fine sandstone.

Loc. 4. a: siltstone, b: conglomeratic tuffaceous sandstone, c: fossil-bearing granule conglomerate, d: siltstone, e: medium loose sandstone, f: laminated siltstone, g: pumice tuff, h: medium massive sandstone.

9. The fossils from the lower horizon, except for these from Loc. 4, have been entirely replaced by clay minerals. The greater portion of clay consists of yellowish iron montmorillonite. While, in the upper horizon, the fossils replaced by montmorillonite were found only in Loc. 6, and in other localities fossils are all moulds and casts.

As the original ostracum structure is still preserved in most of the specimens replaced by clays, the replacement action was probably performed in the form of place-by-place replacement without forming any cavities. These clay minerals may be regarded as derivatives from the pyroclastic materials in the surrounding sediments. The fossil-bearing sediments are invariably tuffaceous, and the fossils are entirely lacking in the non-tuffaceous sediments which occupy the major part of the Togawa formation. From these facts, the replacement by clay mineral may be considered as one of the main factors of the preservation of fossils in this area.

Table 1. X-ray powder data* for clayey material replacing calcium-carbonate of the shells. (Cu Kα radiation, Ni filtered, $\lambda=1.5405$ Å)

Materials from *Mercenaria stimpsoni* (GOULD) (Loc. 1)			Materials from *M. stimpsoni* (Loc. 6)		
d (Å)	I/I$_0$	Mineral species	d (Å)	I/I$_0$	Mineral species
15.6	100 b	Montmorillonite	15.9	100	Montmorillonite
8.50	10		8.26	15	
7.24	5	Kaolin	6.55	15	
5.90	5		4.57	50	Montmorillonite
4.51	40	Montmorillonite	4.27	20	Montm.+Quartz
4.28	20	Montm.+Quartz	3.81	15	
4.05	10	Montmorillonite	3.34	25	Quartz
3.35	30	Quartz	2.56	10 b	Montmorillonite
3.18	10	Plagioclase	2.27	10	
2.83	20	Siderite (?)	2.18	10	
2.59	15 b		1.51	20	Montmorillonite
2.56	15 b	Montmorillonite			
2.23	20			(b=broad)	
1.71	10				
1.67	5				
1.51	25 b	Montmorillonite			

§ 3. Description of Fossil Communities

Each assemblage collected from nine localities has a few species which occupy the considerable part of the population. It is contained in particular sediments, and the majority of the constituents show no marked transportation by water judging from the state of preservation. The writer considers these

fossil assemblages subautochthonous ones, although they may not be the fossil "biocoenosis" in a strict sense. And he regards them as "fossil community" having some ecological relation among the constituents.

Six fossil communities can be recognized among the nine assemblages in view of specific compositions and their quantitative ratios as well as their state of preservation and shell size. Rare species are omitted in discussion to avoid confusion which is liable to result from accidental occurrence.

Each community is named from the exclusive or characteristic species. The term "dominant species" used here refers to numerically exceptionally abundant ones; "exclusive species" denotes the species whose occurrence is restricted in a particular community, or if it is found in other communities, it can be regarded as accidental due to its state of preservation and quantity.

A) *Mercenaria-Peronidia* community

In this community, *Mercenaria stimpsoni* (GOULD) is the most predominant form, although it has the widest distribution and is the most abundant species among the present faunule. The assemblage is characterized by *Tellina* (*Peronidia*) *protovenulosa* NOMURA, *Solen krusensterni* SCHRENCK, *Dosinia japonica* (REEVE), *D. kaneharai* YOKOYAMA, *Panope* cf. *estrellana* CONRAD, etc. *Solen krusensterni* and *Panope estrellana* were found exclusively in this community. They are associated with *Callista* sp., *C. brevisiphonata* (CARPENTER), *Spisula voyi* (GABB), *S.* (*Pseudocardium*) *kurikoma* (NOMURA), *Mactra sulcataria carneopicta* PILSBRY and so on. These associated species are also most common in this community. In addition, *Natica* (*Tectonatica*) sp., *Neptunea* cf. *arthritica* (BERNARDI), *Serripes* cf. *groenlandica* (BRUGUIÈRE), etc., are found, but they are merely a few in number and are regarded as accidental species. A noteworthy fact is that *Echinarachnius* sp. was commonly found in all the assemblages belonging to this community. The occurrence of *Echinarachnius* sp. is exclusive to the community.

Three assemblages from Loc. 1, Loc. 2, and Loc. 3 Upper (3U) are the constituents of the community. The rock containing the community is gravel-bearing, pumiceous, medium-grained sandstone. In Loc. 3 Lower (3L), *Anadara tatunokutiensis nagawensis* occurs in clusters while other species are absent. It is quite different in its composition from Loc. 3U and others, and may belong to the *Fortipecten* community.

Some interesting changes in the constituent species are recognized in these three assemblages. *Panope estrellana* is abundantly found in Loc. 1, or the westernmost of the three localities, and decreases in individual number toward the east. *Dosinia japonica* and *D. kaneharai* are both characteristic species of the community, although their respective occurrence is somewhat different in each. *D. japonica* is common in Loc. 1, and rare in Loc. 2, while *D. kaneharai* is commonly found in Loc. 2 and 3.

B) *Fortipecten* community

Pecten (*Fortipecten*) *kenyoshiensis* CHINZEI is the dominant and exclusive species. *Anadara tatunokutiensis nagawensis* CHINZEI is also exclusive to the community. Other characteristic species are *Mercenaria stimpsoni*, *Spisula* (*Pseu-*

docardium) *kurikoma*, *Glycymeris* cf. *yessoensis* (SOWERBY), etc.   *Venericardia* and *Limopsis* are also restricted to this community.

The community is found in conglomeratic coarse-grained sandstone which consists of andesite and pumice grains with marked cross-lamination. This indicates an environment under fairly mobile water.

Assemblages of Loc. 4 and Loc. 5 belong to the community. The lower part of Loc. 3 (Loc. 3L) may also be included in it judging from the exclusive occurrence of *Anadara tatunokutiensis nagawensis*.

C) *Spisula-Clinocardium* community

The community consists of the assemblage of Loc. 6. *Spisula voyi* (GABB) is the dominant and characteristic species. Other characteristic species are *Clinocardium* sp. 1 and *Mya japonica* JAY. *Tellina* (*Peronidia*) *protovenulosa* and *Mercenaria stimpsoni* are also associated and commonly found in this community.

The community is contained in yellowish medium- to fine-grained sandstone.

In consideration of the occurrence of *Tellina* and *Mercenaria*, this community has an aspect of the *Mercenaria-Peronidia* community, although its stratigraphic horizon is different from the latter. *Spisula voyi* is also found commonly in the latter. As discussed later, the two communities may have inhabited under similar environmental conditions.

D) *Acila-Protothaca* community

Clinocardium sp. 2 is the exclusive species of the community but is less abundant than such characteristic species as *Acila* (*Truncacila*) sp. and *Protothaca adamsi* (REEVE). *Mercenaria stimpsoni* is also commonly found, but is fragmental in most cases.

This is found only at Loc. 7, where the lithology is silty, pumiceous, fine-grained sandstone.

E) *Turritella-Mya* community

The community is composed of *Turritella fortilirata* SOWERBY and *Mya japonica oonogai* MAKIYAMA with *Natica* (*Tectonatica*) sp. and *Macoma* cf. *tokyoensis* MAKIYAMA. The latter two are found only rarely. *T. fortilirata* is the dominant and exclusive species. *M. oonogai* is sometimes found as they lived standing nearly vertically to the stratification. Judging from the above facts, the two species may be both autochthonous. This co-existence of the two species has not yet been reported from the Recent seas. The community is contained in pumiceous, fine-grained massive sandstone. It was found from Loc. 8.

F) *Patinopecten* community

The community is characterized by dominant occurrence of *Pecten* (*Patinopecten*) *sannohensis* CHINZEI accompanied by *Coptothyris grayi* (DAVIDSON). The other characteristic species is *Polytropa shiwa* CHINZEI which is also restricted to this assemblage.

The associated species are *Mercenaria stimpsoni*, *Spisula voyi*, *Mya japonica*, *Anadara* cf. *tatunokutiensis nagawensis* and some others. In general, they do not attain their maximum (or common) size as was measured in other com-

munities.

The assemblage from Loc. 9 represents the community.

The lithology of the rock in which the community is contained is tuffaceous, conglomeratic, coarse-grained sandstone at the basal part of a white, coarse-grained pumice tuff.

The community exhibits a typical character of the so-called " Pecten-Brachiopoda assemblage". This is often found in the sand and gravel bottom of a shelf edge or a submarine ridge where the water movement is active.

§ 4. Considerations on the Habitats of the Communities

Geographical distributions and some interpretations of the habitats of these fossil communities are considered. The *Mercenaria-Peronidia* and the *Fortipecten* communities belong to the lower horizon, while the other four communities to the upper one. The former two are the most important constituents of the faunule.

The *Mercenaria-Peronidia* community is distributed in the southwestern corner of the eastern side of the Tatsunokuchi flexure, nearest to the assumed land area, as seen in the paleogeographic map. The broad distribution of the community and similarity of lithology in each locality indicate that the habitat of the community may be represented by a fairly broad but less varied submarine topography, where the bottom sediment was probably composed of ill-sorted, medium- to coarse-grained sand. The habitat may have been the shallow part of the shelf, judging from the prevalent occurrence of *Tellina*, *Solen*, *Panope*, etc., and from the distribution area of the community.

The *Fortipecten* community was found along the line subparallel to the anticlinal axis. Its habitat may have been fairly deeper than the *Mercenaria-Peronidia* community. This may be supported by the occurrence of *Limopsis* and *Venericardia* in the assemblage of Loc. 4, although they were probably intermingled in this assemblage by accident. Judging from the conglomeratic sediments and their marked cross-lamination, the habitat may have undergone predominant action of wave or current. The direction of distribution, subparallel to the anticlinal axis, may indicate that the zone existed where the movement of water was active. The writer presumes that the habitat of the *Fortipecten* community was situated along the margin of a terrace on which the *Mercenaria-Peronidia* community inhabited.

The horizontal distribution of the species in the lower horizon is illustrated on the left column of fig. 5.

Sediments of the upper horizon consist mainly of medium- to fine-grained sand except for Loc. 9, and the rock facies is fairly uniform in horizontal and vertical directions. The submarine topography may not have been much different in each locality. However, the constituents of the assemblage in each locality are different, so that each assemblage may represent a different community. The *Patinopecten* community is situated in the western limb of the Tatsunokuchi flexuous anticline. This may be quite different in its habitat from

Horizon	Lower						Upper			
Community	Mercenaria-Peronidia				Fortipecten		Spisula-Clinocardium	Acila-Prototh aca	Turritella-Mya	Patinopecten
Species / Locality	1	2	3U	3L	4	5	6	7	8	9
Turritella fortilirata										
Natica (Tectonatica) sp.										
Polytropa freycinetii										
Polytropa shiwa										
Acila (Truncacila) sp.										
Anadara nagawensis										
Fortipecten kenyoshiensis										
Patinopecten sannohensis										
Clinocardium sp. 1										
Callista spp.										
Dosinia japonica										
Dosinia kaneharai										
Mercenaria stimpsoni										
Prototh aca adamsi										
Spisula kurikoma										
Spisula voyi										
Peronidia protovenulosa										
Solen krusensternii										
Panope estrellana										
Mya japonica										
Mya japonica oonogai										

Text-fig. 5. Horizontal distribution of significant species.

other three communities. In the eastern side of the anticline, three communities are arranged from west to east, namely, the *Spisula-Clinocardium*, the *Acila-Prototh aca* and the *Turritella-Mya* communities.

As stated already, the *Spisula-Clinocardium* community resembles the *Mercenaria-Peronidia* community. Many species are common between them. Among the constituent species of the *Spisula-Clinocardium* community, only four species (*Fusitriton oregonensis*, *Macoma* cf. *tokyoensis*, *Siliqua* cf. *alta*, *Mya japonica*) could not be found in the *Mercenaria-Peronidia* community. These four species are also few in individual number in the *Spisula-Clinocardium* community. The both deposits comprising the two communities are massive, tuffaceous, medium-grained sandstone. Thus, it may be presumed that the environments where the two communities lived were somewhat similar each other.

The habitats of the *Patinopecten* and the *Fortipecten* communities are both characterized by conglomeratic sediments which indicate the prevalence of water movement. However, the *Patinopecten* community is different from the *Fortipecten* community in containing the brachiopod species such as *Coptothyris grayi*. The former has the typical composition of "Pecten-Brachiopoda" assemblage. It is very interesting to notice the complete separation of the two pectinids in

such a similar environment and in close distance, although no reasonable explanation has been available. However, it is possible to consider the geographical separation by anticlinal structure which may have produced the submarine swell or peninsula.

Table 2.

| Species	Locality	Number of specimens collected									
		1	2	3U	3L	4	5	6	7	8	9
Turritella (Neohaustator) fortilirata (SOWERBY)			2	2					3	81	
Natica (Tectonatica) sp.			2							2	
Fusitriton oregonensis (REDFIELD) ?								1			
Polytropa freycinetii (DESHAYES)						3					
Polytropa shiwa CHINZEI											3
Neptunea cf. arthritica (BERNARDI)			2								
Acila (Truncacila) sp.			3	1					16		
Limopsis (Empleconia) cumingi A. ADAMS						1					
Anadara tatunokutiensis nagawensis CHINZEI		1			34	8	3				2
Glycymeris cf. yessoensis (SOWERBY)						1	1				
Pecten (Patinopecten) sannohensis CHINZEI											36
Pecten (Fortipecten) kenyoshiensis CHINZEI						41	25				
Venericardia (Cyclocardia) cf. crebricostata (KRAUSE)						1					
Venericardia (C.) aomoriensis CHINZEI						1					
Lucinoma annulatum (REEVE)			1								
Clinocardium sp. 1			2				1	4			
Clinocardium sp. 2								7			
Serripes cf. groenlandica (BRUGUIÈRE)		1									
Callista cf. brevisiphonata (CARPENTER)				1							
Callista sp.		3	1								
Dosinia cf. japonica (REEVE)		5	2								
Dosinia (Kaneharaia) kaneharai YOKOYAMA			3	2			2				
Mercenaria stimpsoni (GOULD)		24	48	28		16	14	3	14		5
Protothaca (Callithaca) adamsi (REEVE)			3					1	12		
Mactra sulcataria carneopicta PILSBRY			2								
Spisula (Pseudocardium) kurikoma (NOMURA)		13	7			9	1				
Spisula (Mactromeris) voyi (GABB)		3	2	3				14			3
Macoma cf. tokyoensis MAKIYAMA								1		1	
Tellina (Peronidia) protovenulosa NOMURA		11	6	8				4			
Siliqua cf. alta (BRODERIP and SOWERBY)								1			
Solen krusensterni SCHRENCK		9	11	3				1			
Panope cf. estrellana (CONRAD)		11	3					1			
Mya japonica JAY								2			2
Mya japonica oonogai MAKIYAMA										22	

§ 5. General Discussion on the Togawa Faunule

The Togawa faunule consists of 34 species in total (6 gastropods and 28 pelecypods). The specific position of 29 forms can be determined. These forms include 20 Recent forms and 9 extinct species 4 of which are new forms and are restricted to the present faunule.

Geographical distribution of the Recent forms

The horizontal distribution of the 20 Recent forms in the west Pacific coast is illustrated in fig. 6. They may be grouped into four distribution patterns. Namely, the A type distributed exclusively to the south of Lat. 35°N, the B_1 type between 35° and 45°, the B_2 type to the north of 39°, and the C type distributed from south to north of 35°. Lat. 35° N roughly corresponds to the northernmost limit of the warm current Kuroshio in winter, and 45° corresponds to the southern limit of freezing area of the sea waters also in winter. The cold current Oyashio has the influence upon the area north of about 35° in winter and about 39° in summer. Thus, the A type species can be regarded as the subtropical elements and the B_1 as those of temperate region and the B_2 as temperate-boreal region. The C type species are said to be the endemic elements of the coastal water around the Japanese Islands.

As clearly shown by fig. 6, the larger parts of the Recent forms of the faunule are represented by the B_1 type elements or the inhabitants of the temperate region of the west Pacific. All the species except *Limopsis cumingi* can be found in the temperate region. Thus, it is concluded that these Recent
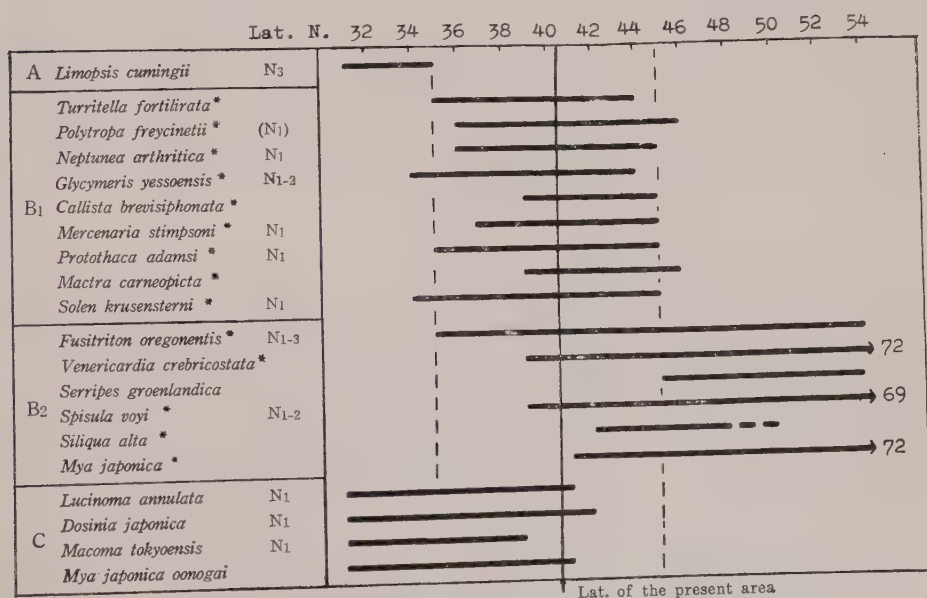
Text-fig. 6. Geographical distributions of the 20 Recent forms in the present seas of the western Pacific coast. Lat. 35° N is the boundary between the subtropical and temperate regions; 45° boundary between the temperate and boreal regions.

forms are, as a whole, inhabitants of the temperate waters. Occurrence of *Limopsis cumingi* in association with the temperate elements deserves attention. It has been regarded as the endemic species of the lower shelf of the warm current Kuroshio region in the Japanese Islands. However, some minor differences of surface ornamentation are recognized between the present specimen and the living *L. cumingi*, so the problem remains unsolved until further comparative studies are carried out.

The Recent forms in the present faunule contain many common species to living assemblage in the seas adjacent to Akkeshi Bay, eastern end of Hokkaido (Lat. 43°N). Among the 20 Recent forms, 14 species were reported from Akkeshi and its neighbourhood (HABE, 1955, 1958a) as asterisked in fig. 6. This also supports the above conclusion.

As the vertical range of the temperate species around Japan is not well known yet, those of the Recent forms of the faunule connot be discussed precisely. The bathymetrical range of several species is shown in fig. 6 after OYAMA's vertical division.* The data are mainly of Central Japan, and in northern region it is considered that the range becomes more or less shallower. Most of the species with their known vertical distribution inhabit the N_1 or euneritic zone (between the lower tidal line and about 30 m in depth), except for *Limopsis cumingi*. As considered also from prevalent occurrence of *Tellina*, *Spisula*, *Solen*, *Panope*, *Mya* etc., the faunule has the characteristic features of the upper (inner) shelf where the coastal water predominates.

Thus, it can be summarized that the Recent forms in the faunule, as a whole, are the upper shelf dwellers in the temperate region of the western Pacific. The general characters of them bear a close resemblance to the molluscan fauna of Akkeshi Bay and adjacent shallow seas of eastern Hokkaido, situated in the northernmost part of the temperate region of the Japanese Islands. The conclusion reached through analysis of the Recent forms well accords with the hitherto known paleoecological characters or paleogeographical distributions of the extinct species in the faunule.

Comparisons with other Japanese Pliocene faunas

The constituent species of the faunule are quite different from these of the Kubo faunule contained in the middle part of the Sannohe group. Among them, only *Fusitriton oregonensis* (REDFIELD) is common with the latter faunule.

There are two distinctly different types of the Pliocene molluscan fauna in Northeast Japan. One of them is the Omma-Manganji fauna and the other is the Tatunokuti fauna. The former is distributed in the Japan Sea side of Honshu, and the latter is found in the Pacific side. The geographical distributions

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* OYAMA (1952) proposed the vertical division of habitat of marine molluscs based mainly on the data obtained from Central Japan. The division is as follows: N_0; tidal zone: N_1; euneritic zone 0–30 m: N_2; mesoneritic zone, 30–60 m: N_3; subneritic zone, 60–120 m: N_4; bathyneritic zone, 120–250 m: NB; hemibathyal zone, 120–250 m, continental slope: B; bathyal zone, 250–1000 m ±, lower half of continental slope: A; abyssal zone, ocean bottom.

of the two faunas are separated by the Ôu mountain range which occupies the central axis of the Uetsu geosyncline of Northeast Japan. The Omma-Manganji type fauna is characterized by cold deep water inhabitants, and is composed chiefly of gastropods accompanied by some pectinid and astartid pelecypods (refer to CHINZEI, 1959), while the Tatunokuti fauna consists of shallow water elements including many endemic pelecypod species (NOMURA, 1938). Another fauna is known from Hokkaido and Sakhalien, which is said to be a mixed fauna of the above two types, and was named the Takikawa fauna.

The Togawa faunule includes both the Tatunokuti and the Omma-Manganji elements. The former is represented by *Pecten* (*Fortipecten*) *kenyoshiensis* and *Anadara tatunokutiensis nagawensis*. *Lucinoma annulatum*, *Panope* cf. *estrellana*, *Solen krusensterni*, *Mya japonica*, etc., are also Tatunokuti elements. On the other hand, *Fusitriton oregonensis*, *Acila* (*Truncacila*) sp., *Glycymeris yessoensis*, *Limopsis cumingi*, *Venericardia* sp., etc., are considered to be the Omma-Manganji forms. In the present faunule, the Tatunokuti elements are abundant in the lower horizon (Locs. 1-5), and the Omma-Manganji types are relatively rich in upper horizon (Locs. 6-8, 9). The typical forms of the two faunas are contained side by side in the *Fortipecten* community.

The mixed character of this faunule shows a similarity to the so-called Takikawa fauna. Moreover, the presence of *Fortipecten*, *Turritella fortilirata*, *Acila* sp. (*gottschei* type), etc., exhibits the close relationship between the faunule and the Takikawa fauna.

However, there are some noteworthy differences between them. The common occurrence of the faunal elements of the Miocene, i.e., *Dosinia kaneharai*, *Spisula* (*Pseudocardium*) *kurikoma* and *Tellina* (*Peronidia*) *protovenulosa*, is the peculiar feature of the faunule and none of these elements has been known from the Takikawa and other Pliocene faunas.

Among the constituents of the Takikawa fauna, the only apparent Tatunokuti element is *Fortipecten takahashii*. Another case of occurrence of Tatunokuti species, *Dosinia tatunokutiensis*, was reported only from northern Hokkaido by HATAI and YOSIDA (1941). In this view, the Togawa faunule bears a closer similarity to the Tatunokuti fauna than to the Takikawa fauna. *Anadara tatunokutiensis* in the present faunule and the Tatunokuti fauna is replaced in the Takikawa fauna (FUJIE, 1958a) by a somewhat similar but undoubtedly different form which can be identified as *A. trilineata calcarea* (GRANT and GALE), the Pliocene arcid of west coast of North America. This is interesting in consideration of the paleo-biogeographical relationship between the west coast of North America and Northeast Japan in Pliocene age.

It seems to be significant that the representative species of the Tatunokuti elements in this faunule, *Fortipecten kenyoshiensis* and *Anadara tatunokutiensis nagawensis*, differ in some important characters from *Fortipecten* and *Anadara* of the typical Tatunokuti fauna. As the latter two have abnormally thick and inflated shells, NOMURA and HATAI (1936a) presumed that the Tatunokuti fauna was under the influence of "peculiar ecologic conditions". The present faunule, however, may be regarded as an ordinary shallow water fauna, since the majority

of constituents of the faunule are common with the coastal water assemblages of the temperate region in the western Pacific. *Fortipecten* and *Anadara* in the present faunule have much thinner shell than *F. takahashii* and *A. tatunokutiensis* (s. str.) as will be discussed in the description of species. They are similar to ordinary *Patinopecten* or other pectinids, and to ordinary *Anadara* respectively. Thus, it is doubtful to conclude that the present faunule was under peculiar conditions similar to those of the Tatunokuti fauna, although it contains species related to the latter.

§ 6. Notes on Mixture of the Miocene Elements

As discussed above, the Togawa faunule has many interesting characters. Among them, the most peculiar aspect is the common occurrence of the species which have hitherto been considered to be restricted in Miocene deposits. They are *Dosinia kaneharai* YOKOYAMA, *Tellina* (*Peronidia*) *protovenulosa* NOMURA and *Spisula* (*Pseudocardium*) *kurikoma* (NOMURA).

Dosinia kaneharai is known from various localities of the Japanese and Korean Miocene, and has been regarded as one of the indicators of the warm water condition of the middle to lower Miocene. Recently, KANNO and TOMIZAWA (1959) reported an occurrence of *D. kaneharai* in association with cold water species *Spisula sachalinensis* (SCHRENCK) and *Serripes makiyamai* (YOKOYAMA) in the Ogawa formation of Central Japan. They concluded that the fauna has mixed character of cold and warm water elements, and so that the geologic age of the Ogawa formation may be younger than other *Dosinia kaneharai*-bearing beds.

Judging from the associated fauna from already known localities of *D. kaneharai*, however, it is more reasonable to conclude that *D. kaneharai* is a temperate water dweller rather than the characteristic species of the subtropical fauna. That is *D. kaneharai* was found always accompanied by all or some of the following species, namely, *Trachycardium shiobarense* (YOKOYAMA), " *Nassarius* " (*Coraeophos*) spp., *Polinices kiritaniana* (YOKOYAMA), *Chlamys kaneharai* (YOKOYAMA), *Diplodonta usta* (GOULD), etc. There are no positive data to verify that these species are warm water inhabitants. In addition, the last mentioned form is known from the present shallow water of warm temperate region surrounding Japan. Typical warm water elements, for example, *Vicarya*, *Vicaryella*, *Conus*, and other members of the Yatsuo-Kadonosawa fauna are entirely absent.*

Spisula (*Pseudocardium*) *kurikoma* and *Tellina* (*Peronidia*) *protovenulosa* were reported for the first time (NOMURA, 1935a) from the upper Miocene Orose formation of central Ôu mountain range. Subsequently, *S. kurikoma* was found in the Itahana formation of North Kwanto by FUJIMOTO and KOBAYASHI (1938),

* In the Sugota formation of Yamagata Prefecture, *D. kaneharai* is reported with *Miogypsina kotoi* HANZAWA (KITAMURA, 1959). This is an exceptional case of the species being associated with a warm element. However, since the detailed biostratigraphical study of the Sugota formation has not yet been accomplished, the associated occurrence of these two forms is still uncertain.

and in the Kitashioko formation in southwestern Abukuma mountains by OMORI (1958), both middle to upper Miocene in age. *Tellina protovenulosa* is reported only from its type locality. However, *T. t-matsumotoi* which seems to be synonymous to *T. protovenulosa*, was reported from the Chikubetsu formation of the middle Miocene of central Hokkaido by some authors (OTUKA, 1940; KANNO and MATSUNO, 1960).

Thus, hitherto known localities of *Spisula kurikoma* and *Tellina protovenulosa* are all restricted in the middle to upper Miocene of northeast Japan.

These three species are the main constituents of the molluscan fauna reported by NOMURA (1935a) from the Orose formation, near Narusawa spa, southwest Iwate Prefecture. After NOMURA's report, the fauna is composed of *Lucina "acutilineata* CONRAD ",* "*Cardium*" *shiobarense* YOKOYAMA, *Dosinia kaneharai* YOKOYAMA, *Tellina protovenulosa* NOMURA, "*Mactra*" *kurikoma* NOMURA, *Panope japonica* (A. ADAMS), "*Nassarius*" *iwakianus* (YOKOYAMA), *Polinices kiritaniana* (YOKOYAMA) and some other pelecypods.

Similar molluscan faunas are found in several localities of Northeast Honshu, which are situated along the central zone of the so-called Uetsu geosyncline. The main part of the central zone was uplifted towards the end of Miocene as discussed by KITAMURA (1959) and some others (FUJIOKA 1956, OMORI 1958). It has been believed that the fauna of the above-mentioned type disappeared from the Uetsu geosynclinal area, and that most of the constituents became entirely extinct by the time when Miocene period was over. In this view, the discovery of these Miocene elements from the upper Pliocene is very interesting.

The writer explains those peculiar phenomena as follows.

The sedimentary basin in which the Sannohe group was accumulated is situated at the northeastern margin of the Uetsu geosyncline. It was initiated in middle Miocene almost contemporaneous with the beginning of depression of the geosyncline and successively submerged till the end of Pliocene. The basin later became the back-basin of the central axis of the geosyncline with the beginning of uplift of the axis at the end of Miocene.

The species under question have not been found in the Miocene formations in this basin. The lower part of the Miocene is the type-locality of the Kadonosawa fauna, which is characterized by the occurrence of subtropical or tropical elements, such as, *Vicarya callosa, Conus tokunagai, Miogypsina kotoi* etc. On the other hand, the upper part of the Miocene deposits is represented by the temperate water fauna, the geologic age of which will be contemporaneous with that of the *D. kaneharai* fauna in the central zone of the geosyncline. The upper Miocene fauna, however, consists of the assemblages of fairly deep water dwellers, and the species common to the latter fauna are almost absent. Thus, this basin in discussion may not involve any environment in favor of the inhabitation of *Dosinia kaneharai* and other species in Miocene time. The environment probably came into existence for the first time in later Pliocene.

Considering these facts, the Miocene type molluscs in the Togawa faunule

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* This may be *L. annulatum* (REEVE), see description of species (p. 110).

is best regarded as the relict forms of the Miocene fauna which had inhabited the central zone of the geosyncline. They might have immigrated into the back-basin along with the uplift of their habitat.

As already suggested by the writer (1959), the occurrence of *Coraeophos meisense ninohense* in the middle horizon of the Sannohe group (Kubo faunule) may be similarly explained. *C. m. ninohense* is closely related to "*Nassarius*" *iwakianus* (YOKOYAMA), one of the main constituents of the *D. kaneharai*-bearing Miocene fauna of the geosyncline.

§ 7.   Conclusive Remarks on the Molluscan
Fauna of the Sannohe Group

The molluscan fauna abundantly contained in the upper half of the Pliocene Sannohe group can be divided into two faunules. They are the Kubo faunule in the middle part of the group and the Togawa faunule in the upper part. The former was previously reported in detail by the writer (1959). It consists chiefly of gastropods, which have been recognized as cold and deep oceanic water (lower shelf) dwellers. The faunal characters are comparable to those of the Omma-Manganji type fauna of the Japan Sea side. Judging from the above facts, the writer has presumed that there was a deep trough between the stable Kitakami mountains in the east and the Ôu mountain range (the central axis of the Uetsu geosynclinal area) in the west, and that the trough had a close zoogeographical connection with the sedimentary terrain of the Japan Sea side in Pliocene age.

In this paper, the writer has clarified that the Togawa faunule has the faunal aspect of the coastal water assemblages of the cold temperate region. The faunule is characterized by the occurrence of Tatunokuti faunal elements, such as *Fortipecten* and *Anadara tatunokutiensis*, associated with the coastal water dwellers of the Recent seas and some Omma-Manganji elements. Thus, the Togawa faunule resembles the "Takikawa fauna" in its mixed character.

An interpretation on relationship among the Pliocene faunas in Northeast Japan

As already mentioned in the preceding section, the Omma-Manganji and the Tatunokuti faunas are found in the basins separated into the Japan Sea side and the Pacific side by the later Miocene orogeny of the central axis of Uetsu geosyncline. The difference between the two faunas has hitherto been considered vaguely to be attributable to the geographical isolation. The Takikawa fauna in Hokkaido is said to have mixed character of above two faunas.

However, the find of the two faunal elements in the same basin leads the writer to conclude that another explanation may be possible for the relationship between the two faunas.

The Kubo and the Togawa formations which contain distinctly different two faunules are the deposits of the later half of the sedimentary cycle which forms the Sannohe group. The Kubo formation represents the middle stage of the cycle, and the Togawa formation the later stage. Judging from the stratigraphy and geologic structure of the basin (CHINZEI, 1958), it was concluded

that the sedimentary environment had changed gradually from the deep and monotonous conditions of the Kubo stage to the shallow and variable conditions of the Togawa stage.

Accordingly, the relation between the two faunules can be concluded as follow: the Kubo faunule lived in the deeper part and the Togawa faunule in the shallower part of the same sedimentary basin. This may indicate that the Tatunokuti fauna represent a shallow coastal water fauna and the Omm-Manganji elements a deep oceanic water ones in the same sea.

In the Togawa faunule, the two elements were found side by side in one locality (see p. 95). This fact also supports the above stated conclusion on the relation between the two faunas.

The Takikawa fauna has been interested because of its mixed character of the Omma-Manganji and the Tatunokuti faunal elements (HATAI and YOSIDA, 1941; MATSUNO and YAMAGUCHI, 1955 etc.). Although detailed biostratigraphical studies of the Pliocene deposits in Hokkaido are scanty, the vertically separated occurrence of the two elements was described by MATSUNO and YAMAGUCHI (1955) from the Embetsu formation of the northwestern coast of Hokkaido. *Pecten (Fortipecten) takahashii*, the representative species of the Tatunokuti element in the Takikawa fauna, is often found exclusively in a particular bed, or found invariably with the shallow water dwellers. Thus, it seems to be more reasonable to presume that the two faunal elements in the Takikawa fauna are contained respectively in different horizons.

In conclusion, the writer inclines to assume the relationship among the three types of the Pliocene molluscan fauna in Northeast Japan as follows. The Omma-Manganji type fauna represents the deep oceanic water environments, and the Tatunokuti fauna occupies the coastal water ones of the same sea. The peculiar

Table 3. Geographic position of the localities.

Loc. 1. Basal part of the cliff, north of Hachiman shrine, northwestern end of Ainai village, Nanbu-machi.

Loc. 2. A path-side small exposure, southwestern end of Torado village, Nagawa-machi.

Loc. 3. A path-side exposure, west of Torado village, Nagawa-machi.

Loc. 4. Near the top of a road-side cutting along the highway between Ken'yoshi and Asamizu, about 500 m west of Ken'yoshi, Nagawa-machi.

Loc. 5. A small exposure in the stream, about 500 m southeast of Kitamuki village, Gonohe-machi.

Loc. 6. A small exposure of the eastern end of Shimodera village, Nagawa-machi.

Loc. 7. A road-side cutting along the highway between Tomabechi and Toyomanai, about 2 km north-northwest of Chibiki Junior High-school, Tomabechi, Chibiki-mura.

Loc. 8. An upper half of a large exposure at 100 m east of Mutsu-Ichikawa railway station, Hachinohe city.

Loc. 9. A cliff in the southern bank of the Asamizu River, 1.2 km west of Dogamae, Nozawa-mura.

All in Sannohe-gun, Aomori Prefecture, Northeast Honshu, Japan.

shape of the constituents and the richness of endemic forms of the Tatunokuti fauna in the type locality may be explained as being caused by the particular ecological conditions in a large and shallow embayment. The Takikawa fauna has been recognized vaguely as the mixture of the two elements. But they occur in respectively different horizons.

§ 8.　Description of Species*

Family Turritellidae

Genus *Turritella* Lamarck, 1799

Turritella (*Neohaustator*) *fortilirata* Sowerby

Plate 3, figure 12.

1914.　*Turritella fortilirata* Sowerby, *Ann. Mag. Nat. Hist., Ser. 8, vol. 14*, p. 36–37, pl. 2, fig. 12.

1934.　*Turritella fortilirata,* Otuka, *Bull. Earthq. Res. Inst., vol. 12, pt. 3*, p. 622, pl. 51, fig. 105.

1938.　*Turritella fortilirata,* Otuka, *Venus, vol. 8, no. 1*, p. 39, text-fig. 29.

1951.　*Turritella fortilirata,* Kotaka, *Short Pap., IGPS, Tohoku Univ., no. 3*, pl. 11, figs. 1, 2.

1952.　*Turritella* (*Neohaustator*) *fortilirata,* Ida, *Geol. Surv. Japun, Rep. No. 150*, p. 53, pl. 4, fig. 1.

1958a.　*Haustator* (*Neohaustator*) *fortilirata,* Habe, *Publ. Akkeshi Mar. Biol. Stat., no. 8*, pp. 9–10, pl. 5, fig. 16.

1959.　*Turritella* (*Neohaustator*) *fortilirata,* Kotaka, *Sci. Rep., Tohoku Univ., ser. 2, vol. 31, no. 2*, pp. 72–73, pl. 4, figs. 1, 9.

Remarks: The general characters of the specimens agree well with the Recent form of *Turritella fortilirata* s. str.; however, the spiral cords of the surface-ornamentation are much narrower than those of the latter, and weak secondary spiral threads are entirely absent.

According to Kotaka (1959), *T. fortilirata* was distributed limitedly in central and eastern Hokkaido in the Pliocene time. In addition, southwestern Hokkaido and the Shimokita Peninsula, the nearest region to the present area, were considered as " *T. fortilirata habei* province ". In view of the biogeographical distribution of *T. fortilirata*, the discovery of *T. fortilirata* s. str. from the present area is very interesting, as the area has hitherto been vaguely considered the southern extension of " *T. fortilirata habei* province ".

Reg. No.: CM 8615–CM 8619.

Occurrences: Turritella-Mya community (exclusive and dominant species). Loc. 8; very abundant, very well preserved but the shell materials were dissolved out, shell large. Most of specimens were lying nearly parallel with bedding plane but distinct orientation of distribution could not be ascertained. *T. fortilirata* was also found from Locs. 2, 3 and 7, although the individual numbers were few and all of them were fragmental specimens.

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* Whole specimens described are preserved in the Institute of Geology, Faculty of Science, University of Tokyo.

Family Naticidae

Genus *Natica* Scopoli, 1777

Natica (*Tectonatica*) sp.

Remarks: As the apertures of the specimens were broken, their precise specific position could not be determined. In outline, the present form closely resembles *Natica* (*Tectonatica*) *severa* Gould.

Reg. No.: CM 8620–CM 8621.

Occurrences: This is a rare species in the faunule. Loc. 2 ; two fairly large but broken specimens. Loc. 8 ; two small specimens.

Family Cymatiidae

Genus *Fusitriton* Cossmann, 1903

Fusitriton oregonensis (Redfield) (?)

See references of Chinzei, (1959). *Fusitriton oregonensis* (Redfield), *Jour. Fac. Sci., Univ. Tokyo, sec. 2, vol. 12, part. 1,* p. 111.

Reg. No.: CM 8622.

Occurrence: *Spisula-Clinocardium* community (accidental occurrence). Only an apical part was found from Loc. 6.

Family Muricidae

Genus *Polytropa* Swainson, 1840

Polytropa freycinetii (Deshayes)

Plate 4, figures 4, 12.

1864. *Purpura Freycinetii* Deshayes, Reeve, *Conch. Icon., vol. 3, Purpura,* pl. 10, sp. 51.
1882. *Purpura Heyseana* Dunker, *Index Moll. Japon.,* p. 40, pl. 13, figs. 10, 11.
1871. *Purpura ? Freycineti* var., Lischke, *Japan. Meer. Conch., vol. 2,* pp. 40–43, pl. 4, figs. 15–19.
1907. *Purpura freycineti,* Hirase, *Conch. Mag., vol. 1, no. 4,* p. 138, pl. 6, figs. 41–43.
1907. *Purpura freycineti* var. *alabaster* Pilsbry, Hirase, *ibid.,* p. 139, pl. 6, fig. 44.
1915. *Thais* (*Nucella*) *lima* Martyn, Dall, *Proc. U. S. Nat. Mus., vol. 49, no. 2124,* pp. 566–567, pl. 75, figs. 4–6.
1927. *Thais lima,* Oldroyd, *Stanf. Univ. Publ., Univ. Ser., Geol. Sci., vol. 2, pt. 2,* p. 44, pl. 36, figs. 4–6.
1934. *Nucella lima freycineti,* Kinoshita and Isahaya, *Rep. Fish. Surv., Hokkaido Fish. Exper. Stat., no. 33,* p. 8, pl. 5, fig. 35.
1934. *Nucella lima freycinetii,* Hirase, *Coll. Japan, Shells,* p. 79, pl. 110, fig. 1.
1958a. *Polytropa freycinetii,* Habe, *Publ. Akkeshi Mar. Biol. Stat., no. 8,* pp. 17–18, pl. 5, fig. 11.

Remarks: Although the surface was strongly worn out, the specimens are comparable to *Polytropa freysinetii* by the pattern of spiral ornamentation and aperture. The characters of the present specimens are summarized as follows: Shell moderate in size, fairly thick, spire low, whorls 4 or more in number ; whorl flattish, weakly shouldered at about 1/3 from the lower suture ;

body whorl large. Surface ornamented with low spiral cords and axial growth lines; primary cords about 12 or 13 on body whorl and 3 on penultimate and the younger whorls; a weak secondary cord is between primary cords. Aperture large, fusiform; inner margin of outer lip weakly folded, inner lip smooth, callus thin; anterior canal broad, semicircle in cross section, basal fasciole thick.

The Recent form of the species is a rocky shore dweller in northern Pacific.

Measurements: Shell height 36.2+mm, maximum diameter 23.1, height of body whorl including canal 32.8, apical angle 72°. Reg. No. CM 8624–CM 8625.

Occurrences: Fortipecten community (exclusive species but few in number). Loc. 4; four specimens, shell common size for the species, two are almost complete specimens and the rests are fragmental, surface worn out.

Polytropa shiwa Chinzei, n. sp.
Plate 2, figures 3, 7, 8.

Diagnosis: Polytropa characterized by evenly inflated whorls and by equally spaced and equally strong spiral cords which are ornamented by densely spaced imbrication of growth lamellae.

Description: Shell medium size for the genus, thick, spire high, whorls 5 except protoconch, protoconch broken; each whorl is fairly inflated but not shouldered, suture distinct, shallowly channeled. Body whorl large, about 3/4 of the shell height. Surface ornamented with nearly equally spaced and equally strong spiral cords, the number of cords is 21 on the body whorl, 7 on the penultimate and 4 on the third whorls. The cords prominent, rounded in profile, breadth nearly equal to their interspaces near the upper part of the body whorl and becomes wider than interspaces towards the base; the surface of cords sculptured with densely spaced and imbricated lamellae. Weak secondary cords are sometimes seen on interspaces at the vicinity of periphery. Aperture large, rounded fusiform; inner margin of outer-lip weakly crenulated; inner-lip smooth, broad and flattish; callus thin, basal fasciole strong; anterior canal narrow but deep, turned backwards.

Remarks: The new species is quite similar to *Polytropa freysinetii* in shell outline and general features of the aperture; however, the new form differs from the latter in the character of spiral cords and much narrower and deeper anterior canal. The spirals of *P. freycinetii* are essentially of alternation of strong primary cord and interstitial secondary cord. In new species, on the other hand, spirals have almost equal strength. Moreover, the surface of cords is ornamented with densely spaced and imbricated lamellae. This character is found in some of *P. freycinetii*, but is much more broadly spaced and more prominent in interspaces than in cords themselves. The name *shiwa* means wrinkles or imbrications in Japanese.

The new species is easily distinguishable from *Polytropa lamellosa* in shell outline and pattern of spiral cords.

The species of *Polytropa* group is highly variable in shape and ornamenta-

tion; however, the essential tendency of these characters, for example, the development of secondary spiral cords and inflation of the whorl, seems to be constant in the species. In this view, the writer determines this form as a new species.

Measurements: Shell length 34.0 mm (except protoconch), length of body whorl 27.7, maximum diameter of body whorl 21.1, length of aperture 20.6, width ca 10, apical angle 68°.

Type-locality: About 1.2 km west of Dogamae, Nozawa-mura (Loc. 9).

Reg. No.: CM 8626 (Holotype), CM 8627–CM 8628 (Paratypes).

Occurrences: Patinopecten community. A single very well preserved specimen and some fragmental specimens were obtained. Their surface sculptures are observable in complete state.

Family Buccinidae

Genus *Neptunea* BOLTEN, 1798

Neptunea cf. *arthritica* (BERNARDI)

1858. *Buccinum arthritica* BERNARDI, *Jour. de Conchyl., vol. 6,* p. 386, pl. 12, figs. 3, 3a.

1934. *Neptunea (Barbitonia) arthritica,* KINOSHITA and ISAHAYA, *Rep. Fish. Surv., Hokkaido Fish. Exper. Stat., no. 33,* p. 9, pl. 6, fig. 45.

1937a. *Neptunea arthritica,* NOMURA and HATAI, *Saito Ho-on Kai Mus., Res. Bull., no. 13,* pp. 1–5, pls. 1, 2, figs. 1–7.

1954. *Neptunea arthritica,* TAKI and OYAMA, *Pal. Soc. Japan, Spec. Pap., no. 2,* pl. 3, fig. 12; pl. 22, fig. 12.

1958. *Neptunea arthritica,* OZAKI, *Bull. Nat. Sci. Mus., vol. 4, no. 1,* p. 151, pl. 19, fig. 19.

1958a. *Neptunea (Barbitonia) arthritica,* HABE, *Publ. Akkeshi Mar. Biol. Stat., no. 8,* p. 22, pl. 2, fig. 16; pl. 4, fig. 5; pl. 5, fig. 13.

1959. *Neptunea (Barbitonia) arthritica,* KIRA, *Colour. Ill. Shells, Japan,* p. 71, pl. 27, fig. 17.

1959. *?Neptunea arthritica,* MAKIYAMA, *Pal. Soc. Japan, Spec. Pap., no. 5,* pl. 69, fig. 4.

Reg. No: CM 8623.

Occurrences: Only two apical parts were obtained from Loc. 2.

Family Nuculidae

Genus *Acila* H. ADAMS and A. ADAMS, 1858

Acila (Truncacila) sp.

Description: Shell small, ovato-trigonal in outline, fairly inflated, inequilateral. Posterior margin gently rounded, anterior margin more sharply curved. Beak situated at posterior 1/3 of the shell length. Surface ornamented with sharply bifurcated radial ribs, none of secondary bifurcation was seen; concentric growth lines especially distinct near the ventral margin. Hinge characters cannot be observed.

Remarks: The specimens closely resemble *Acila (Truncacila) gottschei* (BöHM) of NAGAO and HUZIOKA (1941) and *A. kurodai* KANEHARA (1941) which was considered a synonym of *A. gottschei* by NAGAO and HUZIOKA. However, the writer hesitates to name the specimens "*gottschei*" because of poor preservation of them.

They can be separable from *Acila insignis* by more anteriorly situated beaks.

All the specimens are 10 mm or more or less in length, and are much smaller than ordinary *gottschei*.

Measurements: Length 12.5 mm, Height 10.0, thickness ca 3.5 ; a left valve.

Reg. No.: CM 8629–CM 8631.

Occurrences: Acila-Protothaca community (dominant and exclusive species). Loc. 7 ; abundant, conjoined or odd valves, complete or fragmental. *Mercenaria-Peronidia* community (accidental occurrence). Locs. 2 and 3, rarely found from both localities, fragmental specimens.

Family Limopsidae

Genus *Limopsis* SASSI, 1827

Limopsis (Empleconia) cf. *cumingi* A. ADAMS

Plate 1, figures 6, 7.

1862. *Limopsis cumingi* A. ADAMS, *Proc. Zool. Soc. London*, p. 229.
1922. *Limopsis areolata* YOKOYAMA, *Jour. Coll. Sci., Imp. Univ. Tokyo, vol. 44, art. 1,* p. 194, pl. 17, figs. 6, 7.
1951. *Limopsis (Empleconia) cumingii,* HABE, *Gen. Japan. Shells, Pelec.,* p. 44, figs. 75, 76.
1953. *Limopsis (Empleconia) cumingii,* HABE, *Illust. Cat. Japan. Shells, vol. 1, no. 25,* p. 203, pl. 29, figs. 1, 5.
1954. *Limopsis (Empleconia) cumingii,* TAKI and OYAMA, *Pal. Soc. Japan, Spec. Pap., No. 2,* pl. 37, figs. 6, 7.
1958b. *Limopsis (Empleconia) cumingii,* HABE, *Publ. Seto Mar. Biol. Labor., vol. 6, no. 3,* p. 258, pl. 13, fig. 3.

Remarks: The postero-dorsal margin of the specimen is deeply folded inwards so as to form a lunule-like depression, and the surface is ornamented with well marked concentric growth lines and many weaker but distinct radial striations. *L. cumingi* A. ADAMS reported originally from Goto Isls., western Kyushu, is characterized by lunule-like depression of the postero-dorsal margin, but has no distinct radial sculptures. Although the present specimen has distinct radial striations, the writer refferred it to *L. cumingi* tentatively.

Measurements: Left valve. Length 16.3 mm, height 16.4, thickness 4.1, length of hinge plate 8.2, length of ligamental area 4.0.

Reg. No.: CM 8632.

Occurrences: Fortipecten community. Loc. 4 ; only one left valve, rather small size, surface more or less worn.

Family Arcidae

Genus *Anadara* GRAY, 1847

Anadara (Anadara) tatunokutiensis nagawensis CHINZEI, n. subsp.

Plate 2, figures 1, 4, 9–12.

Diagnosis: Anadara tatunokutiensis characterized by thin test. Ribs bipartite, 30 to 32 in number ; posterior shoulder almost invisible, posterior end produced. Beak small, slender.

Description: Shell large, subquadrate or fan-shaped in outline, elongated antero-posteriorly. Test rather thin. Nearly equivalve, inequilateral. Beak prominent, slender, situated at about anterior two fifths of the shell length. Antero-dorsal margin shouldered; anterior margin regularly curved and extends gradually to ventral margin; ventral margin circular, gently arcuated; postero-dorsal margin nearly straight, without any marked shoulder; posterior end protruded and rather sharply bent towards the ventral margin. Surface ornamented with 30 to 32 radial ribs, ribs quadratic in section, width nearly equal to or a little narrower than their interspaces. Surface of the rib separated by a distinct furrow into two ridges and sometimes each ridge bifurcated again near the ventral margin, the ridges much narrower than the furrows. Hinge area rather delicate, cardinal area fairly broad, both sides of the triangular area straight, sculptured by 3 or 4 chevron grooves. Teeth strongest at the both ends of the hinge and rapidly weaken towards the central part. Anterior muscle scar semicircular, posterior one subrounded. Inner margin strongly crenulated.

Comparison: The new subspecies differs from typical *A. tatunokutiensis* (Nomura and Hatai) (1936a) in its less inflated and much more thinner test, slender and pointed beak, larger number of radial ribs and slender ribs. The new form also resembles *Anadara devincta* (Conrad) and its subspecies reported form the Miocene and the lower Pliocene of west coast of North America. Especially *A. devincta montesanoana* (Etherington) is quite similar to the new form in its prolonged posterior margin and nearly straight postero-dorsal margin. However, the latter can be distinguished from *montesanoana* by its larger shell, pointed beak, narrow radial ribs and less number of chevron grooves.

Anadara tatunokutiensis and its subspecies *nagawensis* n. subsp. can be separable from *Anadara trilineata amicula* (Yokoyama) by larger shell and antero-posteriorly more elongated outline. They are also distinguished from *A. trilineata* (Conrad) s. str., a Pliocene arcid of west coast of North America, by shell outline and larger number of radial ribs. *Andara trilineata calcarea* (Grant and Gale) reported by Fujie (1958a) from the Pliocene Takikawa fauna of Hokkaido resembles the present new form and typical *tatunokutiensis* in shell outline, but differs distinctly in feature of ligamental area.

Remarks: In the juvenile stage, the shell outline is more quadrate than adult, somewhat similar to that of *A. amicula*, and then the posterior end extends with growth.

Anadara tatunokutiensis (Nomura and Hatai) (1936a, pp. 68–70, pl. 12, figs. 1, 2) was reported from the Tatunokuti formation in the environs of Sendai, and is characterized by large size and very heavy test. Nomura and Hatai discussed the abnormally thickening of test and regarded it as a "reflection of peculiar environmental conditions" referring to the conclusion of Grant and Gale (1931) on *Anadara trilineata* var. *calcarea*.

The present new subspecies, accompanied by the usual oceanic water assemblage as stated foregoing discussion, has ordinarilly thick shell. In this view, the find of normal form of *tatunokutiensis* may support indirectly the

opinion of NOMURA and HATAI. The present new subspecies may be an usual form of *A. tatunokutiensis* as *Pecten (Fortipecten) kenyoshiensis* was considered to be an usual form of *Pecten (F.) takahashii*.

Measurements (in mm):

Specimen	Reg. No.	Valve	Length	Height	Thick-ness	Hinge length	Ligamen-tal area	Number of ribs	Position of beaks*
Holotype	CM 8633	R	62.0	49.3	17.9	41.1	34.4×6.1	31	26.5
Paratype 1	CM 8634	//	67.1	51.2	19.6	44.7	37.0×7.5	31	29.4
// 2	// 8635	//	75.0	ca53	ca20	ca48	—	29+	33.2
// 3	// 8636	//	ca64	ca43	16.6	37.8	29.0×6.0	30	ca23
// 4	// 8637	L	70.6	48	20.6	40.2	31.8×8	30	ca28
// 5	// 8638	//	ca49	38.7	13.3	28.6	25.3×4.8	32	ca20

* from anterior   (all specimens from the type locality)

Type locality: About 500 m west of Ken'yoshi town, Nagawa-machi (Loc. 5). *Reg. No.:* CM 8633-CM 8642.

Occurrences: Fortipecten community (exclusive and characteristic species). Loc. 4; common, well preserved, seldom fragmental, shell attains largest size: Loc. 5; few, shell large. Loc. 3L; very abundant, exclusive species, all specimens rather small size, conjoined valves commonly found, the original shell-materials were replaced by halloysite-like clay mineral. Other Occurrences: Loc. 1; One broken specimen, shell large: Loc. 9; few, shell small.

Family Glycymeridae

Geuus *Glycymeris* DA COSTA, 1778

Glycymeris cf. *yessoensis* (SOWERBY)

1888. *Pectunculus yessoensis* SOWERBY, *Proc. Zool. Soc. London*, p. 570, pl. 28, fig. 19.
1920. *Pectunculus yessoensis*, YOKOYAMA, *Jour. Coll. Sci., Imp. Univ. Tokyo, vol. 39, art. 6*, p. 168, pl. 18, figs. 1, 2.
1922. *Pectunculus yessoensis*, YOKOYAMA, *ibid., vol. 44, art. 1*, pp. 189-190, pl. 16, figs. 6, 7.
1925c. *Pectunculus yessoensis*, YOKOYAMA, *Jour. Fac. Sci., Imp. Univ. Tokyo, vol. 1, pt. 1*, p. 20, pl. 4, fig. 4.
1930. *Glycymeris yessoensis*, MAKIYAMA, *Venus, vol. 2, no. 3*, pp. 107-116, Text-figs. 1-9, figs. 1, 2.
1934. *Glycymeris yessoensis*, KINOSHITA and ISAHAYA, *Rep. Fish. Surv., Hokkaido Fish. Exper. Stat., no. 33*, p. 12, pl. 9, fig. 63.
1935b. *Glycymeris yessoensis*, NOMURA and HATAI, *Saito Ho-on Kai Mus., Res. Bull., no. 6*, pp. 93-95, pl. 9, fig. 14.
1936b. *Glycymeris yessoensis*, NOMURA and HATAI, *ibid., no. 10*, p. 118, pl. 13, fig. 8.
1951. *Glycymeris (Glycymeris) yessoensis*, HABE, *Gen. Japan. Shells, Pelec.*, p. 41, figs. 65, 66.
1954. *Glycymeris yessoensis*, TAKI and OYAMA, *Pal. Soc. Japan, Spec. Pap., no. 2*, pl. 19, figs. 1, 2, pl. 36, figs. 6, 7.
1955. *Glycymeris yessoensis*, HABE, *Publ. Akkeshi Mar. Biol. Stat., no. 4*, p. 3, pl. 2, figs. 1, 2.
1958. *Glycymeris yessoensis*, YAMAMOTO and HABE, *Bull. Mar. Biol. Stat. Asamushi, Tohoku Univ., vol. 9, no. 1*, pp. 6-7, pl. 2, figs. 25, 26, pl. 4, fig. 8.
1958b. *Glycymeris yessoensis*, FUJIE, *Cen. Res., Sapporo, no. 28*, p. 32, pl. 27, figs. 1-15.
1958b. *Glycymeris yessoensis*, HABE, *Publ. Seto Mar. Biol. Lab., vol. 6, no. 3*, p. 256, pl. 12, fig. 16.

1958. *Glycymeris* (*Glycymeris*) *yessoensis*, OZAKI, *Bull. Nat. Sci. Mus., vol. 4, no. 1*, p. 113, pl. 23, fig. 6.

1959. *Glycymeris yessoensis*, KIRA, *Colour. Ill. Shells, Japan*, p. 113, pl. 44, fig. 10.

1959. *Glycymeris* (*Glycymeris*) *yessoensis*, IWAI, *Sci. Rep., Fac. Educ. Hirosaki Univ., no. 5*, p. 55, pl. 2, figs. 5a, b.

Reg. No.: CM 8643, CM 8644.

Occurrences: Fortipecten community. Locs. 4 and 5; some poorly preserved specimens (fragmental) were obtained, shells attain the usual size of the species.

Family Pectinidae

Genus *Pecten* MÜLLER, 1776

Pecten (*Patinopecten*) *sannohensis* CHINZEI, n. sp.

Plate 1, figures 1-5.

Diagnosis: Patinopecten characterized by 19 to 21 squarish sometimes dichotomously branched ribs on right valve; and by low, triangular, smooth ribs on left valve. Distinct secondary riblets are absent.

Description: Shell medium for *Patinopecten*, height larger than length, ventricose, nearly equilateral except for auricles. Surface ornamented with 19 to 21 prominent radial ribs and fine growth lines. Hinge line nearly straight or weakly concave, its length slightly less than one half of shell length. Apical angle 105° to 110°.

Right valve fairly inflated for *Patinopecten*. Surface ornamented with 19 to 21 smooth, squalish, prominent radial ribs; ribs sometimes become dichotomously or rarely trichotomously branched on the ventral half of the shell, medial sulcus of ribs shallow but broad; interspaces of ribs narrow, width about one half of ribs. Anterior auricle slightly larger than posterior; byssal notch shallow, byssal area not depressed, smooth; both auricles ornamented by several low, radial riblets except for byssal area. Hinge with shallow subtriangular resilifer pit, with fairly prominent cardinal ridges bordering the anterior and posterior sides of the pit, and with a distinct ridge running subparallel to hinge line.

Left valve ornamented with smooth radial ribs, fine reticulated network, and concentric growth lines which become distinct near the ventral margin. Radial ribs prominent, narrowly rounded or almost triangular in profile; interspaces much broader than ribs; secondary riblets are absent on ribs; faint radial striations are sometimes seen on rib-interspaces. Anterior auricles slightly larger than posterior, weakly undulated. Both auricles ornamented with low, narrow riblets. Resilifer pit deep, triangular, bordered by distinct furrows on both sides; ligamental area broad.

Comparison and Remarks: The new species most closely resembles *Pecten* (*Patinopecten*) *ninohensis* MASUDA and *P. tryblium* YOKOYAMA, especially in the branching of ribs. However, it is distinguishable from the latter two in squalish, more prominent ribs of the right valve and simple ornamentation of the left valve. *Pecten* (*Patinopecten*) *healeyi* ARNOLD has prominent, squalish, dichotomously branched ribs similar to *sannohensis* n. sp. But the medial sulcus

on ribs of *healeyi* becomes as deep as the rib-interspaces near the ventral margin, while in *sannohensis*, medial sulcus is still very shallow. Some characters of the new species and the allied forms are summarized in table 4.

Table 4. Comparisons of *Pecten (Patinopecten) sannohensis* CHINZEI n. sp. with allied species.

species name	number of rib	right valve		characters of ribs in left valve	apical angle
		branching of ribs	other features		
sannohensis CHINZEI n.sp.	19–20	sometimes bipartite in the ventral half	prominent, squalish in section	prominent, triangular in section, secondary riblets absent	105°-110°
ninohensis MASUDA	20±	bipartite near the antero- and posero-margins, sometimes tripartite	low, rounded, smooth	round-topped, faint radial threads in the dorsal side	100° ±
tryblium YOKOYAMA	18–22	bipartite in the ventral half	low, borad, surface flat	prominent, triangular	110°-115°
yessoensis JAY	20±	rarely bipartite	low, borad, very weak threads are seen	low, narrow, smooth	110° ±
healeyi ARNOLD	18–21	bipartite, sometimes tripartite, medial sulcus very deep near the ventral margin	prominent, squalish	narrow, rounded, prominent riblets occur in the inter-spaces	120°-125°

Pecten ninohensis MASUDA (1954) may be considered a form most closely related to the new species, judging from its general outline, characters of ribs and hinge elements. The type specimens of *ninohensis* are rather small ones among the topotypes; the adult shell attains generally 70 to 80 mm or more long. It is very interesting that *P. ninohensis* was reported from the lower horizon (Upper Miocene) of the same sedimentary basin than that of the new species was found, and another occurrence has not yet been reported.

Measurements (in mm):

Specimen	Reg. No.	Valve	Length	Height	Thickness	Hinge length	Number of ribs	Apical angle
Holotype	CM 8645	R	80.3	ca85	19.0	ca38	20	107°
Paratype	CM 8646	"	ca63	ca68	12.6	29.5	21	100
"	" 8647	"	ca52	54.7	9.5	28.4	19	108
"	" 8648	L	60.5	64.3	6.6	ca28	20	106
"	" 8649	"	66.8	ca70	—	32.0	19 or 20	106
"	" 8650	"	59.7	60.5	6.4	ca31	21	107
"	" 8651	R	68.0	ca72	12.3	—	20	103
"	" 8652	"	ca80	ca90	ca15	ca39	20	106

(all specimens from the type-locality)

Type locality: About 1.2 km west of Dogamae, Nozawa-mura (Loc. 9).

Occurrences: *Patinopecten* community (dominant and exclusive species of the community).   Loc. 9; very abundant, well preserved but fragile, original shell materials are preserved, found as odd valves with convex side above.

Pecten (Fortipecten) kenyoshiensis Chinzei

1960.   *Pecten (Fortipecten) kenyoshiensis* Chinzei, *Japan. Jour. Geol. Geogr., vol. 32, no. 1,*
      pp. 64–67, pl. 7, figs. 1–7, text-figs. 1, 2.

Remarks: The species is characterized by broad ribs and by thinner test than *Fortipecten takahashii* (Yokoyama).   It exhibits the morphologically inter-mediate character between *Fortipecten takahashii* and *Patinopecten.*   This may be due to difference in environmental conditions as well as due to geo-graphical isolation.   Judging from the associated species, the environment of the present faunule as a whole might have been under ordinary conditions as compared with those of *F. takahashii.*

Occurrences: *Fortipecten* community (dominant and exclusive species of the community).   Locs. 4 and 5; in Loc. 4, the surface is slightly worn, all speci-mens were found as odd valves with convex side above.

Family Carditidae

Genus *Venericardia* Lamarck, 1801

Venericardia (Cyclocardia) cf. *crebricostata* (Krause)

1885.   *Cardita borealis* var. *crebricostata* Krause, *Archiv. Naturges., vol. 51,* p. 30, pl. 3,
      fig. 4.
1890.   " *Venericardia borealis* Conrad ", Stearns, *Proc. U. S. Nat. Mus., vol. 13,* pp. 215–
      216, pl. 16, fig. 8.
1902.   *Venericardia alaskana* Dall, *Proc. Acad. Nat. Sci. Philad., vol. 54,* p. 710.
1924a.   *Venericardia crebricostata,* Oldroyd, *Stanf. Univ. Publ., Geol. Sci., vol. 1, no. 1,* p.
      114, pl. 13, fig. 12.
1939.   *Venericardia crebricostata,* Otuka, *Jour. Geol. Soc. Japan, vol. 46, no. 544,* p. 28,
      pl. 2, figs. 3, 4.
1951.   *Venericardia (Cyclocardia) crebricostata,* Habe, *Gen. Japan. Shells, Pelec.,* p. 108,
      figs. 210–212.

Remarks: A poorly preserved specimen of right valve and some fragments are at hand.   They have ovato-triangular outline and have 20 or 21 low radial ribs.   Although the shell surface was worn out and slightly deformed by com-pression, the specimen of right valve may be comparative to *V. crebricostata* judging from its shell outline and number of ribs.

It is not impossible to regard the present specimen as a juvenile shell of *V. aomoriensis* n. sp., although the shell outline does not agree with it.

Measurements: Length 23.3, height 22.6, thickness 6.7 mm. Reg. No. CM 8654.

Occurrences: *Fortipecten* community.   Loc. 4, only a small right valve, the outer surface was fairly worn out, some fragmental specimens were also found.

Venericardia (Cyclocardia) aomoriensis Chinzei, n. sp.

Plate 1, figures 9–11.

Diagnosis: *Cyclocardia* characterized by large and thick test, nearly circular outline. Ribs about 21 in number, low but broad.

Description: Shell large for subgenus, very thick, nearly circular in outline; moderately inflated; almost equilateral except for deep lunule. Beak large but not prominent, fairly pointed. Antero-dorsal margin concave near the beak with deeply depressed lunule being elongate cordate in shape; rest of the margin evenly rounded. Surface ornamented with about 21, rather low broad ribs, the breadth of ribs almost equal to that of rib-interspaces; concentric growth lines lamellated. Hinge thick and heavy, an elevated large cardinal tooth is at the center and shallow cardinal sockets are on the both sides of the tooth in the right valve; the anterior sockets shallow and almost degenerated. Left valve unknown. Inner surface thick; muscular impression deep, anterior one slightly larger than posterior; a small triangular muscular impression-like depression is between anterior muscle scar and cardinal teeth; margin weakly undulated.

Remarks: A right valve with worn surface is at hand. It is characterized by almost circular outline and large and very thick shell. None of such a circular *Cyclocardia* has been reported from areas adjacent to Japan or from other areas as far as the writer's observation is concerned.

The new species resembles *V. crebricostata* (Krause) in large size and about 21 low broad ribs. But in general, *V. crebricostata* has ovate-triangular outline and the maximum length is only about 2/3 of the present specimen. *Venericardia orbica* Yokoyama (1925b, p. 8, pl. 1, fig. 10) has also nearly circular outline, although it can be distinguished from the present species by lower shell and larger number of radial ribs (about 30 according to Yokoyama's description).

Measurements: Length 38.6 mm, height 40.6, thickness 11.2.

Type locality: About 500 m west of Ken'yoshi, Nagawa-machi (Loc. 4).

Reg. No.: CM 8655 (Holotype).

Occurrences: Only from *Fortipecten* community. A right valve from Loc. 4; the surface is fairly worn out, but inner surface is well preserved.

Family Lucinidae

Genus *Lucinoma* Dall, 1901

Lucinoma annulatum (Reeve)

1850.   *Lucina annulata* Reeve, *Conch. Icon.*, vol. 6, *Lucina*, pl. 4, sp. 17.

1920.   *Lucina borealis* (Linné), Yokoyama, *Jour. Coll. Sci., Imp. Univ. Tokyo*, vol. 39, art. 6, pp. 133–134, pl. 10, fig. 7.

1923.   *Lucina borealis*, Yokoyama, *Japan. Jour. Geol. Geogr.*, vol. 2, no. 3, p. 57, pl. 6, fig. 11.

1935a.   *Lucina (Myrtea) acutilineata* Conrad, Nomura and Hatai, *Saito Ho-on Kai Mus., Res. Bull.*, no. 5, pp. 9–10, pl. 2, figs. 3, 4.

1938.   *Lucina (Lucinoma) acutilineata*, Nomura, *Sci. Rep., Tohoku Imp. Univ.*, ser. 2, vol.

19, no. 2, p. 253, pl. 35, fig. 5.

1951. *Lucinoma annulata*, HABE, *Gen. Japan. Shells, Pelec.*, p. 129, figs. 277, 278.

1954. *Lucinoma concentrica* YOKOYAMA, TAKI and OYAMA, *Pal. Soc. Japan, Spec. Pap.*, *no. 2*, pl. 11, fig. 7.

1957. *Lucinoma annulata*, MAKIYAMA, *ibid., no. 3*, pl. 7, fig. 11.

1958. *Lucinoma acutilineata*, OZAKI (part), *Bull. Nat. Sci. Mus., vol. 4, no. 1*, p. 125, pl. 21, fig. 3.

1958b. *Lucinoma annulata*, FUJIE, *Cenoz. Res., Sapporo, no. 28*, p. 37, pl. 28, fig. 21.

1959. *Lucinoma annulata*, YAMAMOTO and HABE, *Bull. Mar. Biol. Stat. Asamushi, vol. 9, no. 3*, p. 90, pl. 6, figs. 24, 25.

1959. *Lucinoma annulata*, KIRA, *Colour. Ill. Shells, Japan*, p. 133, pl. 53, fig. 2.

Remarks: The species is distinguishable from *L. acutilineatum* (CONRAD) by more densely spaced concentric lamellae of surface ornamentation. This is the upper shelf and coastal water inhabitant against the lower shelf dweller *L. acutilineatum*.

Measurements: Length 27.9, height 24.3, thickness 5.4 mm. (CM 8656).

Occurrence: *Mercenaria-Peronidia* community (accidental species?). Loc. 2; a specimen, adult.

Family Cardidae

Genus *Clinocardium* KEEN, 1938

Clinocardium sp. 1

Plate 3, figure 9.

Remarks: Some poorly preserved specimens were obtained. The characters are briefly described as follows: Shell rather small for the genus, well inflated, ventricose; beak pointed, situated closer to anterior; the anterior end narrowly rounded and extends steeply to the ventral margin; posterior margin broadly rounded; surface ornamented with low, rounded radial ribs, about 23 in number; ribs broader than their interspaces; lateral teeth of two sides thick and long; cardinals inaccessible.

The specimens resemble *Clinocardium shinjiense* (YOKOYAMA) and *C. ciliatum* (FABRICIUS) in shell outline, although they differ from the latters in less number of radial ribs.

Measurements (*in mm*):

Specimen	Reg. No.	Valve	Length	Height	Thickness	Number of ribs
1	CM 8657	R	33.4	31.0	9.7	23 ?
2	CM 8658	L	22.7	22.2	6.9	21
3	CM 8659	R	41.8	38.8	11.3	23
4	CM 8660	"	19.3	17.1	4.9	—

(all specimens from Loc. 6)

Occurrence: *Spisula-Clinocardium* community (characteristic species of the community). Loc. 6; common, fragments were also found. Other occurrences: Loc. 2; few small and fragmental specimens. Loc. 5; rare, a broken specimen.

Clinocardium sp. 2

Remarks: Only several fragmental specimens are at hand. They are much larger than preceeding *Clinocardium* sp. 1, and have much more squalish ribs.

Reg. No.: CM 8663.

Occurrences: *Acila-Protothaca* community (exclusive species). Loc. 7; common, both conjoined and separated valves were found, fragmental specimens were also collected.

Genus *Serripes* Beck, 1841

Serripes cf. *groenlandica* (Bruguière)

1929. *Cardium groenlandicum* Chemnitz, Yokoyama, *Jour. Fac. Sci., Imp. Univ. Tokyo, vol. 2, pt. 9,* p. 390, pl. 73, figs. 2, 3.
1933. ? *Serripes groenlandicus* (Bruguière), Nomura, *Japan. Jour. Geol. Geogr., vol. 11, nos. 1-2,* pp. 6-7, pl. 1, fig. 8.
1954. *Serripes groenlandicus* Gmelin, Hirayama, *Sci. Rep. Tokyo Kyoiku Daigaku, Sec. C, no. 18,* pp. 67 68, pl. 4, fig. 3.
1959. *Serripes groenlandica,* Makiyama, *Pal. Soc. Japan, Spec. Pap., no. 5,* pl. 71, figs. 2, 3.

Remarks: A poorly preserved specimen was collected. The specimen can be compared with *Serripes groenlandica* in relatively lower shell and the surface sculpture having densely spaced fine radial ribs.

Occurrences: *Mercenaria-Peronidia* community (may be an accidental occurrence). Loc. 1; a right valve, the beak was destroyed and the surface was almost worn out (CM 8664).

Family Veneridae

Genus *Callista*, Poli, 1791

Callista cf. *brevisiphonata* (Carpenter)

Plate 3, figure 10.

1866. *Saxidomus brevisiphonatus* Carpenter, *Proc. Zool. Soc. London, 1865,* pp. 203 204.
1929. ? *Macrocallista brevisiphonata,* Yokoyama, *Jour. Fac. Sci., Imp. Univ. Tokyo, vol. 2, pt. 9,* p. 388, pl. 75, fig. 4.
1934. *Callista brevisiphonata,* Hirase, *Coll. Japan. Shells,* p. 19, pl. 34, fig. 4. .
1934. *Callista brevisiphonata,* Kinoshita and Isahaya, *Rep. Fish. Surv., Hokkaido Fish. Exper. Stat., no. 33,* p. 16, pl. 12, fig. 87.
1955. *Callista brevisiphonata,* Habe, *Publ. Akkeshi Mar. Biol. Stat., no. 4,* pp. 12-13, pl. 3, figs. 7, 8.
1958b. *Callista brevisiphonata,* Fujie, *Cen. Res., Sapporo, no. 28,* p. 38, pl. 27, figs. 25, 26.
1959. *Callista brevisiphonata,* Yamamoto and Habe, *Bull. Mar. Biol. Stat. Asamushi, vol. 9, no. 3,* pp. 94-95, pl. 8, figs. 8, 9.
1959. *Ezocallista brevisiphonata,* Kira, *Colour. Ill. Shells, Japan,* p. 141, pl. 56, fig. 4.
1959. ? *Callista brevisiphonata,* Makiyama, *Pal. Soc. Japan, Spec. Pap., no. 5,* pl. 73, fig. 4.

Remarks: The specimen is quite similar to *Callista brevisiphonata* (Carpenter) in shell outline and surface sculpture. The hinge is characteristic of *Callista* having three strong cardinal teeth and a deep triangular anterior lateral socket. However, it has much deeper and broader posterior cardinal socket than ordi-

nary *brevisiphonata*. *C. brevisiphonata* is a common inhabitant in shallow waters between northern Japan and the Kurile Islands.

Measurements: Length 52.1, height 39.6, thickness 9.8 mm. Reg. No. CM 8665.

Occurrences: *Mercenaria-Peronidia* community. Loc. 3; only a single right valve, well preserved, shell somewhat smaller than adults of the Recent specimens.

Callista sp.

Plate 4, figures 7, 11.

Description: Shell rather small for the genus, elongate oval, inflated, beak prominent, situated at about one-third of the length; anterior margin narrowly rounded, posterior margin broad, evenly rounded, ventral margin ventricose. Surface sculptured by weak growth line. Hinge fairly broad, showing characteristic features of *Callista* with pointed anterior lateral tooth and large triangular posterior cardinal tooth. Pallial sinus short and broad.

Remarks: The specimens are distinguishable from *Callista brevisiphonata* (CARPENTER) in higher and more inflated shell. They are characterized by broad postero-ventral margin. In hinge character the specimens resemble *Callista yamamotoi* KUBOTA (1949), but they can easily distinguished from the latter by shell outline.

Measurements (in mm):

Specimen	Reg. No.	Locality	Valve	Length	Height	Thickness
1	CM 8666	Loc. 2	R	48.4	37.0	12.8
2	CM 8668	Loc. 1	L	45.6	36.7	12.6
3	CM 8667	//	R	ca51	45.4	12.0

Occurrences: *Mercenaria-Peronidia* community (Exclusive species of the community but few in number). Loc. 1; 3 in number, preservation common. Loc. 2; a single specimen, well preserved.

Genus *Dosinia* SCOPOLI, 1777

Dosinia cf. *japonica* (REEVE)

Plate 3, figure 8.

1850. *Artemis Japonica* REEVE, *Conch. Icon., vol. 6, Artemis*, pl. 3, sp. 17.
1855. *Artemis Japonica*, SOWERBY, *Thes. Conch., vol. 2*, p. 669, pl. 143, fig. 60.
1934. *Dosinia (Phacosoma) japonica*, HIRASE, *Coll. Japan. Shells*, p. 17, pl. 31, fig. 4.
1935a. ? *Dosinia japonica*, NOMURA, *Saito Ho-on Kai Mus., Res. Bull., no. 5*, pp. 84–86, pl. 3, fig. 5.
1951. *Dosinia (Phacosoma) japonica*, HABE, *Gen. Japan. Shells, Pelec.*, p. 169, fig. 384.
1959. *Dosinia (Phacosoma) japonica*, YAMAMOTO and HABE, *Bull. Mar. Biol. Stat. Asamushi, vol. 9, no. 3*, p. 46, pl. 8, figs. 5, 6.

1959. *Dosinia (Phacosoma) japonica*, Kira, *Colour. Ill., Shells, Japan*, p. 141, pl. 56, fig. 7.

Remarks: The specimens can be discriminated from *Dosinia kaneharai* Yokoyama in the same assemblage by its shell outline, such as, relatively lower shell, deeper lunule, angulated posterior end, evenly rounded ventral margin, and by deep and narrow pallial sinus. *D. troscheli* Lischke closely resembles *D. japonica* so that the discrimination is difficult. Kuroda (1931) considered the former a subspecific form of *D. japonica*, and Nomura (1935a) regarded it as merely a synonimic rank. There are some differences among the Recent forms of the two species as described by Kira (1959).

Measurements (in mm):

Specimen	Reg. No.	Locality	Valve	Length	Height	Thickness
1	CM 8670	Loc. 1	R	58.6	52.6	13.0
2	CM 8671	//	//	44.2	40.8	9.5
3	CM 8672	//	L	ca65	60.5	15.7
4	CM 8673	//	conjoined	43.6	39.0	10.0×2
5	CM 8675	Loc. 2	R	56.7	50.3	11.0
6	CM 8676	//	//	52.4	49.0	10.0

Occurrences: *Mercenaria-Peronidia* community (exclusive and characteristic species). Loc. 1; common, well preserved, a small specimen was found with conjoined valves. Loc. 2; few, well preserved, common size.

Dosinia (Kaneharaia) kaneharai Yokoyama

Plate 3, figures 1, 7.

1926a. *Dosinia kaneharai* Yokoyama, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, vol. 1, pt. 4*, p. 133, pl. 17, figs. 1-5, pl. 18, fig. 2.
1935b. *Dosinia kaneharai*, Nomura, *Saito Ho-on Kai Mus., Res. Bull., no. 5*, pp. 83-84, pl. 3, figs. 6-8.
1936b. *Dosinia kaneharai*, Nomura and Hatai, *ibid, no. 10*, p. 128, pl. 14, fig. 2.
1936. *Dosinia kaneharai*, Nomura and Zinbo, *ibid.*, p. 339, pl. 20, fig. 1.
1936. *Dosinia (Kaneharaia) kaneharai*, Makiyama, *Mem. Coll. Sci., Imp. Univ. Kyoto, Ser. B, vol. 11, no. 4*, p. 214, pl. 4, fig. 2.
1936. *Dosinia (Kaneharaia) kaneharai*, Otuka, *Bull. Earthq. Res. Inst., vol. 14, pt. 3*, pp. 442, 443, fig. 3.
1940. *Dosinia kaneharai*, Nomura and Onisi, *Japan. Jour. Geol. Geogr., vol. 17, nos. 3-4*, p. 183, pl. 17, figs. 2-7.
1955. *Dosinia (Kaneharaia) kaneharai*, Kanno, *Trans. Proc. Pal. Soc. Japan, n. s., no. 19*, p. 82, pl. 13, figs. 7a, b.
1958. *Dosinia (Kaneharaia) kaneharai*, Makiyama, *Pal. Soc. Japan, Spec. Pap., no. 4*, pl. 35, figs. 1-5, pl. 36, fig. 2.
1959. *Dosinia (Kaneharaia) kaneharai*, Kanno and Tomizawa, *Trans. Proc. Pal. Soc. Japan, n. s., no. 33*, pp. 11-12, pl. 2, figs. 1a, b, 2, 3.

Remarks: Six specimens are considered to belong to *Dosinia kaneharai* judging from shell outlines, surface sculptures and form of pallial sinus. The shell is characterized by acute apical angle, shallow lunule, not angnlated an-

terior and posterior ends. Surface is sculptured with many flat, concentric cords separated by much narrower furrows. Short but broad pallial sinus is one of the most characteristic features of *D. kaneharai*.

D. kaneharai has hitherto been considered by most authors a typical warm water species of the middle or lower Miocene in Japan. However, as already stated, it may be more reasonable to conclude that the species is one of the cold water inhabitants than to regard it as a characteristic species of warm water elements.

Measurements (in mm):

Specimen	Reg. No.	Locality	Valve	Length	Height	Thickness
1	CM 8677	Loc. 2	R	ca41	ca41	10. 8
2	CM 8678	"	"	ca44	45. 7	11. 0
3	CM 7680	Loc. 3	L	41. 2	38. 1	10. 3
4	CM 8681	"	R	48. 5	49. 0	11. 6
5	CM 8682	Loc. 5	L	ca50	—	—

Occurrences: The specimens were not derived from the lower horizons, because the state of preservation is equal to other associated forms and the occurrence of the species considerably common in some localities.

Mercenaria-Peronidia community (exclusive and characteristic species). Loc. 2; common, some specimens broken, surface ornamentation well preserved. Loc. 3; few, normal preservation. Other occurrence; Loc. 5; rare, common size, broken.

Genus *Mercenaria* SCHUMACHER, 1817

Mercenaria stimpsoni (GOULD)

Plate 2, figures 5, 6; Plate 3, figure 5.

1922. *Venus (Mercenaria) stimpsoni* GOULD, YOKOYAMA, *Jour. Coll. Sci., Imp. Univ. To-kyo, vol. 44, art. 1*, p. 148, pl. 11, figs. 11, 12.

1926c. *Chione chitaniana* YOKOYAMA, *Jour. Fac. Sci., Imp. Univ. Tokyo, sec. 2, vol. 1, pt. 9*, pp. 352–353, pl. 39, fig. 13.

1931. *Chione (?) chitaniana*, KURODA in HOMMA, *Geol. Middle Shinano, pt. 4*, pp. 58–59, text-fig. 6.

1951. *Mercenaria stimpsoni*, HABE, *Gen. Japan. Shells, Pelec.*, p. 172, figs. 387, 388.

1954. *Mercenaria stimpsoni*, TAKI and OYAMA, *Pal. Soc. Japan, Spec. Pap., no. 2*, pl. 31, figs. 11, 12.

1954. *Mercenaria stimpsoni*, HAYASAKA and UOZUMI, *Trans. Proc. Pal. Soc. Japan, n. s., no. 15*, pp. 169–170.

1955. *Mercenaria stimpsoni*, HABE, *Publ. Akkeshi Mar. Biol. Stat., no. 4*, p. 13, pl. 5, figs. 10, 11.

1958. *Mercenaria chitaniana*, MAKIYAMA, *Pal. Soc. Japan, Spec. Pap., no. 4*, pl. 51, fig. 13.

Remarks: Many well preserved specimens were collected from Loc. 4. They differ from the Recent specimens of *M. stimpsoni*, living in shallow waters of northern Japan, in the respect of much smaller test in adult shell and more rounded posterior end. Most of the specimens have many radial striations on

shell surface; however, these are columuar structures of ostracum exposed by erosion. In shell outline this species resembles *Mercenaria yokoyamai* (Makiyama), but it can be distinguished from *yokoyamai* by more compressed shell (fig. 7).

The distinction between *M. stimpsoni* and *M. yokoyamai* is exhibited in a triangular diagram, three end members of which represent length, height and thickness of the shell.

M. yokoyamai has hitherto been considered a synonym of *M. chitaniana* (Yokoyama) (1926c, pp. 352–353, pl. 39, fig. 13). However, the type specimen* of *M. chitaniana* falls in the central area of *M. stimpsoni* field of the triangular diagram. *M. chitaniana* of Otuka (1940, pp. 95–96, pl. 11, figs. 9, 12) and of
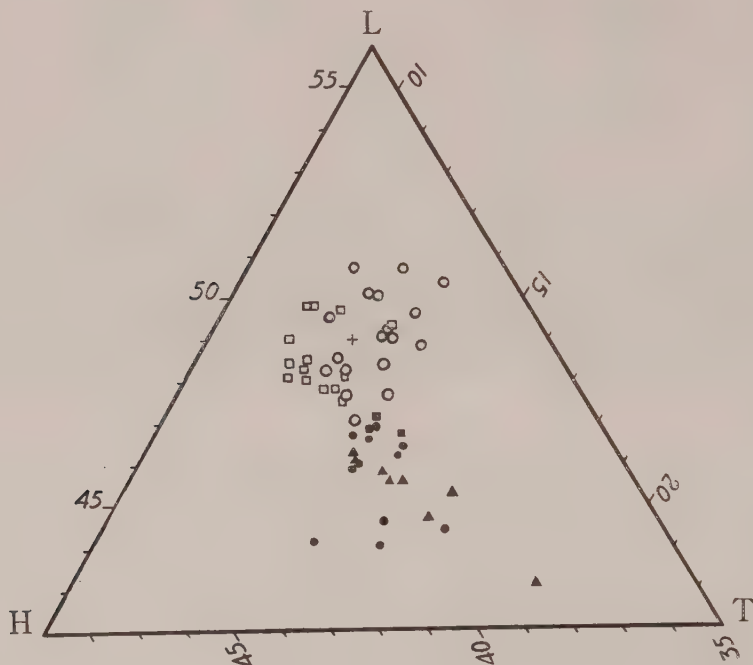
Text-fig. 7. Diagram showing the differences between *Mercenaria stimpsoni* (Gould) and *M. yokoyamai* (Makiyama).

L: Length, H: Height, T: Thickness, (L+H+T=100)

□····*M. stimpsoni* (Recent forms)

○····*M. stimpsoni* (specimens from the present faunule)

+····Holotype of "*Chione chitaniana* Yokoyama" (after Yokoyama, 1926c)

■····Type specimens of *M. yokoyamai* (Makiyama) (after Makiyama, 1927)

●····*M. yokoyamai* (specimens from the upper Miocene Fujina formation of Izumo, western Honshu, topotypes)

▲····*M. yokoyamai* (from various localities in Japan, Hayasaka & Uozumi, 1954, etc.)

* The specimen preserved in the Geological Survey of Japan was destroyed by air raid during World War II, and so, the Yokoyama's original measurements (1926c, p. 353) are the only available data.

HAYASAKA and UOZUMI (1954, pp. 166–168, pl. 22, figs. 2a, 2b, 5a, 5b), *Venus chitaniana* of NOMURA (1938, pp. 260–261, pl. 33, fig. 17), *Chione chitaniana* of YOKOYAMA (1927, p. 201, pl. 51, figs. 3, 4) and of KURODA (1931, pp. 58–59, text-fig. 6) agree with the type specimens of *M. yokoyamai* (MAKIYAMA) (1927, pp. 46–47, pl. 2, fig. 8). *M. chitaniana* may be a synonym of *M. stimpsoni*, and *M. yokoyamai* is a valid name for " *M. chitaniana* " auct. nom.

Measurements (*in mm*):

Specimen	Reg. No.	Locality	Valve	Length	Height	Thick-ness	Ratio (%) of		
							Length	Height	Thick-ness
1	CM 8684	Loc. 1	L	65.5	52.4	17.5	48.4	38.7	12.9
2	CM 8685	"	"	64.5	49.0	15.6	50.0	38.0	12.0
3	CM 8686	"	R	61.4	44.9	14.7	50.7	37.1	12.2
4	CM 8687	"	"	72.5	54.4	16.0	50.7	38.1	11.2
5	CM 8688	"	L	46.0	33.4	9.0	50.3	36.5	13.2
6	CM 8689	"	"	49.0	38.0	12.5	49.2	38.2	9.8
7	CM 8690	"	"	50.3	38.8	13.9	48.8	37.7	13.5
8	CM 8692	Loc. 2	R	57.0	43.0	15.0	49.6	37.4	12.6
9	CM 8693	"	"	59.0	46.7	13.4	49.5	39.2	11.3
10	CM 8694	"	"	47.1	40.1	13.0	47.0	40.0	12.8
11	CM 8695	"	"	57.0	44.3	14.7	49.0	38.2	12.8
12	CM 8696	"	con-joined	55.2	42.0	13.0 (left)	50.1	38.1	12.8
13	CM 8697	"	L	52.5	41.0	13.5	49.1	38.3	12.6
14	CM 8700	Loc. 4	R	64.0	53.6	15.2	48.2	40.4	11.4
15	CM 8701	"	"	63.1	51.1	15.8	48.5	39.6	12.2
16	CM 8702	"	L	64.2	53.8	17.0	47.6	39.9	12.3
17	CM 8703	"	"	60.0	49.3	15.3	48.2	39.6	12.6
18	CM 8704	"	"	58.7	48.0	16.5	47.6	39.0	13.4

Occurrences: This is the most abundant species and has broadest distribution in this faunule. *Mercenaria-Peronidia* community (dominant species) and *Fortipecten* community (characteristic species). Loc. 1; abundant, well preserved, test replaced by montmorillonite-like clay minerals, shell attains largest size. Loc. 2; very abundant, some specimens are conjoined valves. Loc. 3; very abundant, conjoined valves are common. Loc. 4; abundant, very well preserved. Loc. 5; common. Other occurrences: Loc. 9; few, rather small, broken specimens. Loc. 6; few, well preserved, large. Loc. 7; common, broken and fragmenral specimens.

<div align="center">

Genus *Protothaca* DALL, 1902

Protothaca (*Callithaca*) *adamsi* (REEVE)

Plate 1, figure 8.

</div>

1863.   *Venus Adamsi* REEVE, *Conch., Icon., vol. 14, Venus*, pl. 17, sp. 77.
1927.   *Venus rigida* GOULD, YOKOYAMA, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, vol. 1,*

pt. 10, p. 430, pl. 50, figs. 3, 4.

1934. *Protothaca adamsi*, HIRASE, *Coll. Japan. Shells*, p. 22, pl. 41, fig. 2.

1937. *Protocallithaca adamsi*, NOMURA, *Saito Ho-on Kai Mus., Res. Bull., no. 13*, p. 10, pl. 3, figs. 4a, 4b.

1951. *Callithaca adamsi*, HABE, *Gen. Japan. Shells, Pelec.*, p. 180, figs. 391–392.

1954. *Protothaca (Callithaca) adamsi*, TAKI and OYAMA, *Pal. Soc. Japan, Spec. Pap., no. 2*, pl. 47, figs. 3, 4.

1955. *Callithaca (Protocallithaca) adamsi*, HABE, *Publ. Akkeshi Mar. Biol. Stat., no. 4*, p. 14, pl. 5, figs. 1, 2.

1957. *Protothaca (Callithaca) adamsi*, OZAKI, FUKUTA and ANDO, *Bull. Nat. Sci. Mus., vol. 3, no. 3*, p. 172, pl. 31, fig. 31.

1957. *Protothaca (Callithaca) adamsi*, OYAMA, *Moll. Shells, No. 1, Protothaca*, figs. 5, 5a.

1958. *Protothaca (Callithaca) adamsi*, OZAKI, *Bull. Nat. Sci. Mus., vol. 4, no. 1*, pp. 129–130, pl. 22, fig. 1.

1959. *Callithaca (Protocallithaca) adamsi*, YAMAMOTO and HABE, *Bull. Mar. Biol. Stat. Asamushi, vol. 9, no. 3*, p. 98, pl. 7, fig. 16.

Remarks: *Protothaca adamsi* is a species common in the coastal waters of northern Japan.

Measurements (in mm):

Specimen	Reg. No.	Locality	Valve	Length	Height	Thickness
1	CM 8710	Loc. 2	L	52.3	43.8	12.5
2	CM 8711	"	R	44.4	35.4	9.8
3	CM 8713	Loc. 7	L	61.5	47.1	14.1

Occurrences: *Acila-Protothaca* community (characteristic species). Loc. 7; abundant, very well preserved, conjoined valves commonly found, broken and fragmental specimens also common. Loc. 2; few, well preserved, rather small in size. Loc. 6; rare, a small specimen, well preserved.

Family Mactridae

Genus *Mactra* LINNÉ, 1767

Mactra sulcataria carneopicta PILSBRY

1904. *Mactra carneopicta* PILSBRY, *Proc. Acad. Nat. Sci. Philad., vol. 56*, p. 550, p. 39, figs. 1-3.

1934. *Mactra sulcataria carneopicta*, KINOSHITA and ISAHAYA, *Rep. Fish. Surv., Hokkaido Fish. Exper. Stat., no. 33*, p. 18, pl. 14, fig. 100.

1934. *Mactra sulcataria carneopicta*, HIRASE, *Coll. Japan, Shells.*, p. 28, pl. 50, fig. 8.

Remarks: The specimen can be discriminated from *Mactra sulcataria* REEVE by having antero-posteriorly elongated shell, and having densely spaced growth line.

Reg. No.: CM 8716.

Occurrences: *Mercenaria-Peronidia* community. Only from Loc. 2; a left valve, the dorsal half of the surface was worn out.

Genus *Spisula* Gray, 1837

Spisula (Pseudocardium) kurikoma (Nomura)

Plate 4, figures 2, 3, 5, 6, 8, 10, 14.

1935a. *Mactra kurikoma* Nomura, *Saito Ho-on Kai Mus., Res. Bull., no. 5*, pp. 92-93, pl. 3, figs. 2-4.

Remarks: The specimens may be identical with *S. kurikoma* judging from the following characters.

Shell moderate in size for *Pseudocardium*, ovate-trigonal in outline, test thick. Beak large, prominent, antero-dorsal margin rounded, postero-dorsal margin nearly straight or weakly arcuated, ventral margin ventricose, anterior end produced. Surface sculptured by irregular coarse growth lamellae. Hinge heavy with mactroid teeth; acute triangular chondrophore is behind triangularly arranged small cardinal teeth; lateral teeth very heavy; angle between anterior and posterior lateral teeth 95° to 115°. Pallial sinus broad, rather short, rounded at end. Muscular impressions large, subrounded, strongly impressed.

The species has many characters common with *Spisula (Pseudocardium) sachalinensis* (Schrenck); however, it is easily distinguishable from the latter by much smaller size, less inflated postero-dorsal margin and more acute angle between anterior and posterior lateral teeth. *S. kurikoma* is characterized by subtrigonal outline and high beak.

This is most allied to *Pseudocardium densatum* (Conrad) among the Japanese *Pseudocardium*. Woodring et al. (1940) pointed out that *Mactra sachalinensis* Schrenck is a Recent representative form of *Pseudocardium* (Gabb, 1866). Their conclusion was ascertained by Oyama (1958) who included *Pseudocardium* tentatively in *Spisula* as a subgenus. The present species is safely included within *Pseudocardium* from its thick shell and ventricose outline.

Measurements (in mm):

Specimen	Reg. No.	Locality	Valve	Length	Height	Thickness
1	CM 8717	Loc. 1	R	58. 8	52. 4	20. 2
2	CM 8718	"	L	58. 0	48. 3	15. 0
3	CM 8719	"	"	63. 0	58. 1	19. 0
4	CM 8720	"	"	54. 3	50. 0	14. 9
5	CM 8721	"	R	56. 9	48. 0	15. 0
6	CM 8722	"	"	55. 3	.45. 6	14. 2
7	CM 8723	Loc. 2	"	48. 7	41. 2	13. 0

Reg. No.: CM 8717–CM 8729.

Occurrences: Shells may have been fragile. *Mercenaria-Peronidia* community (characteristic species) and *Fortipecten* community (associated species). Loc. 1; abundant, fairly well preserved, but surface stripped off in most specimens, shell attains largest size. Loc. 2; some small specimens, preservation normal. Loc. 4; common, original shell materials were preserved but most of them were

broken down when collected, shell small. Loc. 5 ; a small, fairly well preserved specimen.

Spisula (Mactromeris) voyi (GABB)

Text-figure 8. [*]

1869.   *Callista voyi* GABB, *Pal. California, vol. 2*, p. 24, pl. 5, fig. 4.

1916.   *Spisula voyi*, PACKARD, *Univ. Calif. Publ., Bull. Dept. Geol., vol. 9*, pp. 283-285, pl. 13, fig. 4 ; pl. 14, figs. 1, 2 ; pl. 15, figs. 1a, 1b, 2.

1924a.   *Spisula voyi*, OLDROYD, *Stanf. Univ. Publ., Geol. Sci., vol. 1, no. 1*, p. 193, pl. 23, figs. 1, 2.

1924b.   *Spisula (Hemimactra) voyi*, OLDROYD, *Publ. Puget Sound Biol. Stat., vol. 4*, p. 59, pl. 38, figs. 1, 2.

1925a.   *Spisula grayana* (SCHRENCK), YOKOYAMA, *Jour. Coll. Sci., Imp. Univ. Tokyo, vol. 45, art. 5*, p. 17, pl. 2, fig. 11.

1925c.   *Spisula grayana*, YOKOYAMA, *Jour. Fac. Sci., Imp. Univ. Tokyo, sec. 2, vol. 1, pt. 1*, p. 11, pl. 4, fig. 3.

1927.   ? *Spisula grayana*, YOKOYAMA, *ibid., vol. 2, pt. 4*, p. 199, pl. 52, fig. 7.

1929.   *Spisula grayana*, YOKOYAMA, *ibid., vol. 2, pt. 9*, p. 387, pl. 74, fig. 11.

1931.   *Mactra polynyma voyi*, GRANT and GALE, *Mem. San Diego Soc. Nat. Hist., vol. 1*, p. 395.

1937b.   *Spisula voyi*, NOMURA and HATAI, *Saito Ho-on Kai Mus., Res. Bull., no. 13*, p. 139, pl. 20, fig. 8.

1940.   ? *Spisula polynyma voyi*, NOMURA, *Sci. Rep., Tohoku Imp. Univ., ser. 2, vol. 21*, p. 29, pl. 1, fig. 17.

1957.   *Spisula grayana*, MAKIYAMA, *Pal. Soc. Japan, Spec. Pap., no. 3*, pl. 17, fig. 11.

1958.   *Spisula polynyma voyi*, MAKIYAMA, *ibid., no. 4*, pl. 28, fig. 3.

Remarks : *Spisula voyi* is characterized by its large shell and anteriorly situated beak as originally described by GABB (fide PACKARD, 1916).

A Recent form called " *S. polynyma voyi* " by Japanese malacologists, which inhabits in northwestern Pacific, does not coincide with GABB's type in its shell outline and hinge character. It closely resembles *Spisula polynyma* STIMPSON and may be regarded as a subspecies of the latter.
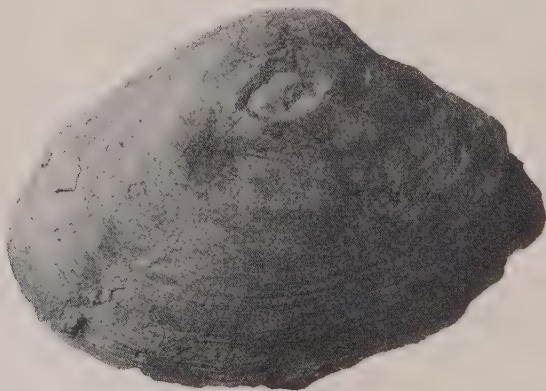
Text-fig. 8. *Spisula (Mactromeris) voyi* (GABB),
from Loc. 6, CM 8730. ×3/5

Spisula onnechiuria (OTUKA) (1936) reported from the upper Miocene of Teshio province, Hokkaido is quite similar in outline with PACKARD's specimen (Pl. 15, fig. 2) judging from OTUKA's original figure.

Most of the specimens collected here are moulds, so the detailed surface features are unknown. Their characters are summarized as follows: Shell large for the species, beak situated slightly closer to anterior, antero-dorsal margin weakly concave, postero-dorsal margin gently convex, anterior end rather sharply rounded, ventral margin gently and evenly arcuated. Hinge of right valve is identical to that of PACKARD's figure (Pl. 14, fig. 2). The present specimens have a little more sharply arcuated anterior end than other *voyi* hitherto reported.

Measurements (in mm):

Specimen	Reg. No.	Locality	Valve	Length	Height	Thickness	Position of beak from anterior
1	CM 8730	Loc. 6	R	125.0	86.7	26.0	55.4
2	CM 8732	Loc. 1	"	99.2	69.9	18.7	44.9
3	CM 8734	Loc. 2	"	97.4	64.4	18.3	44.0
4	CM 8736	Loc. 3	"	65.6	53.5	13.7	28.5
5	CM 8737	"	L	87.1	63.0	15.4	36.8

Occurrences: Spisula-Clinocardium community (dominant species). Loc. 6; abundant, well preserved, shell attains largest. The species also found subordinately in the *Merceanria-Peronidia* community, Loc. 1; small specimens, Loc. 2; a few broken specimens, Loc. 3; some large specimens. Loc. 9; poorly preserved small specimens.

<center>Family Tellinidae</center>

<center>Genus *Macoma* LEACH, 1819</center>

<center>*Macoma* cf. *tokyoensis* MAKIYAMA</center>

<center>Plate 2, figure 2.</center>

1920. *Macoma dissimilis* (MARTENS), YOKOYAMA, *Jour. Coll. Sci., Imp. Univ. Tokyo, vol. 39, art. 6*, pp. 116-117, pl. 7, figs. 19, 20.

1922. *Macoma dissimilis*, YOKAYAMA, *ibid., vol. 44, art. 1*, p. 143, pl. 10, fig. 4.

1925a. *Macoma dissimilis*, YOKAYAMA, *ibid., vol. 45, art. 5*, p. 20, pl. 5, fig. 9.

1925b. ? *Macoma dissimilis* ?, YOKOYAMA, *ibid., art. 7*, p. 6, pl. 1, fig. 19.

1926a. *Macoma dissimilis*, YOKOYAMA, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, vol. 1, pt. 4*, p. 133, pl. 16, fig. 4.

1928. *Macoma tokyoensis* MAKIYAMA, *Mem. Coll. Sci., Imp. Univ. Kyoto, vol. 3, no. 1*, p. 50 (foot note).

1929. ? *Macoma dissimilis*, YOKOYAMA, *Jour. Fac. Sci., Imp. Univ. Tokyo, sec. 2, vol. 2, pt. 9*, p. 388, pl. 74, fig. 2.

1934. *Macoma tokyoensis*, OINOMIKADO, *Venus, vol. 4, no. 6*, p. 353, pl. 8, figs. 12, 13, text-figs. 1-3.

1935a. ? *Macoma tokyoensis*, NOMURA, *Saito Ho-on Kai Mus., Res. Bull., no. 5*, pp. 88-90, pl. 4, fig. 12.

1935b.   *Macoma tokyoensis*, NOMURA, *ibid.*, pp. 115-116, pl. 7, figs. 7, 8.

1940.   *Macoma tokyoensis*, NOMURA and ONISI, *Japan. Jour. Geol. Geogr., vol. 17, nos. 3-4*, p. 184, pl. 18, fig. 6.

1954.   *Macoma incongrua* (v. MARTENS), TAKI and OYAMA, *Pal. Soc. Japan, Spec. Pap., no. 2*, pl. 8, figs. 19, 20.

1954.   *Macoma tokyoensis*, TAKI and OYAMA, *ibid.*, pl. 30, fig. 4.

1956.   *Macoma* (s. s.) *tokyoensis*, TSUCHI, *Rep. Lib. Arts Fac., Shizuoka Univ., Nat. Sci., no. 9*, p. 52, fig. 9.

1957.   *Macoma tokyoensis*, MAKIYAMA, *Pal. Soc. Japan, Spec. Pap. 3*, pl. 20, fig. 9.

1957.   *Macoma* (*Macoma*) *tokyoensis*, OZAKI, FUKUTA and ANDO, *Bull. Nat. Sci. Mus., vol. 3, no. 3*, p. 173, pl. 32, fig. 44.

1958.   *Macoma tokyoensis*, OZAKI, *ibid., vol. 4, no. 1*, p. 133, pl. 23, fig. 5.

1958.   *Macoma tokyoensis*, ITOIGAWA, *Mem. Coll. Sci., Univ. Kyoto, ser. B, vol. 24, no. 4*, pp. 253, 258, pl. 2, fig. 3.

1958.   *Macoma tokyoensis*, MAKIYAMA, *Pal. Soc. Japan, Spec. Pap., no. 4*, pl. 34, fig. 4.

1959.   *Macoma tokyoensis*, YAMAMOTO and HABE, *Bull. Mar. Biol. Stat. Asamushi, vol. 9, no. 3*, p. 104, pl. 14, figs. 9-11.

Remarks: The specimens may be identical with *Macoma tokyoensis* in the shell outline and the form of pallial sinus.

Reg. No.:   CM 8740, CM 8741.

Occurrences: *Macoma* was found only rarely in this faunule. *Spisula-Clinocardium* community : Loc. 6 ; a well preserved but small specimen. *Turritella-Mya* community : Loc. 8 ; some broken specimens.

<div align="center">

Genus *Tellina* LINNÉ, 1758

Tellina (*Peronidia*) *protovenulosa* NOMURA

Plate 3, figures 6, 11 ; Plate 4, figures 1, 9, 13.

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1927.   *Tellina venulosa* SCHRENCK, YOKOYAMA, *Jour. Fac. Sci., Imp. Univ. Tokyo, sec. 2, vol. 2, pt. 4*, pp. 199-200, pl. 52, fig. 5.

1929.   *Tellina venulosa*, YOKOYAMA, *ibid., vol. 2, pt. 9*, pp. 387-388, pl. 72, fig. 6.

1935a.   *Tellina protovenulosa* NOMURA, *Saito Ho-on Kai Mus., Res. Bull., no. 5*, pp. 87-88, pl. 3, fig. 11 ; pl. 4, figs. 7-9.

1940.   *Tellina* (*Peronidia*) *lutea t-matumotoi* OTUKA, *Japan. Jour. Geol. Geogr., vol. 17, nos. 1-2*, pp. 96-97, pl. 11, figs. 7, 8.

Remarks: *T. protovenulosa* NOMURA is characterized by subtrigonal outline, anteriorly situated beak, protruded posterior end and almost straight ventral margin.   NOMURA's original description does not coincide with his illustrations. That is, he described the position of beak as "located a little posteriorly" and also stated that "anterior part considerably longer than the posterior". However, judging from his illustration and explanation (Pl. 4, figs. 7-9, "mould of right valves, paratype"), the beaks of these specimens are situated fairly anteriorly.   The holotype (Pl. 3, fig. 11) is a left valve* although he explained as "mould of right valve, type".   Thus, it is obvious that NOMURA took the left valve for right.

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* Reexamination of the holotype was made by Dr. T. KOTAKA of the Tohoku University upon the writer's request.   Taking this opportunity, the writer expresses his sincere thanks to Dr. KOTAKA.

Tellina lutea t-matumotoi was reported by OTUKA from the lower Chikubetsu beds of Teshio, Hokkaido. The type specimens of *t-matumotoi* may be a young shell of *T. protovenulosa* because they agree well with small specimens of the present collection. *T. protovenulosa* resembles *T. venulosa* (SCHRENCK) in general features, but they are easily separable by the position of beak and shell outline.

The present specimens are described as follows: Shell large attaining 70 mm long, elongate subtrigonal in outline, compressed, slightly inequivalve, inequilateral; left valve more inflated than right, posterior end weakly twisted to right. Beak situated at about anterior 3/7 of shell length. Antero-dorsal margin gently arcuated, anterior end fairly rounded, postero-dorsal margin straight or slightly convex, posterior end protruded and sometimes truncated, ventral margin almost straight or slightly arcuated. Surface sculptured by weak and dense growth lines. A low broad rib-like swell is at the internal surface running from beak to back of anterior muscle scar. Hinge composed of a pair of small cardinal teeth and a faint lateral tooth-like swell at anterior. Pallial sinus invisible.

Measurements (in mm):

Specimen	Reg. No.	Locality	Valve	Length	Height	Thickness	Position of beak from anterior	Apical angle
1	CM 8742	Loc. 1	R	68. 4	39. 7	6. 1	29. 0	133°
2	CM 8743	"	L	64. 4	39. 1	5. 3	30. 0	128
3	CM 8744	"	"	61. 5	34. 7	5. 2	28. 5	135
4	CM 8745	"	R	46. 1	22. 6	3. 6	22. 0	138
5	CM 8746	"	L	50. 7	28. 7	4. 6	21. 8	128
6	CM 8747	"	"	48. 2	27. 0	3. 5	21. 2	131
7	CM 8749	Loc. 2	R	31. 0	16. 0	1. 9	15. 7	132
8	CM 8750	"	"	64. 9	35. 0	5. 0	30. 0	133
9	CM 8752	Loc. 3	L	46. 0	28. 8	5. 2	27. 0	133
10	CM 8753	"	"	60. 6	35. 1	5. 4	28. 5	132

Occurrences: *Mercenaria-Peronidia* community (characteristic species) and *Spisula-Clinocardium* community (associated species). Loc. 1; abundant, well preserved, shell rather small. Loc. 2; common, well preserved. Loc. 3; common, shell large, broken specimens. Loc. 6; few, very well preserved, shell large.

Family Solenidae

Genus *Siliqua* MEGERLE von MÜHLFELD, 1811

Siliqua cf. *alta* (BRODERIP and SOWERBY)

1924a. *Siliqua patula alta* (BRODERIP and SOWERBY), OLDROYD, *Stanf. Univ. Publ., Geol. Sci., vol. 1, no. 1,* p. 190, pl. 47, figs. 1, 2.

1929. *Siliqua costata* (SAY), YOKOYAMA, *Jour. Fac. Sci., Imp. Univ. Tokyo, sec. 2, vol. 2, pt. 9,* p. 387, pl. 72, figs. 3–5.

1931. *Siliqua alta,* GRANT and GALE, *Mem. San Diego Soc. Nat. Hist., vol. 1,* pp. 388–389,

pl. 21, fig. 1.

1934. *Siliqua patula alta*, KINOSHITA and ISAHAYA, *Rep. Fish. Surv., Hokkaido Fish. Exper. Stat., no. 33*, p. 17, pl. 14, fig. 98.

1934. *Siliqua alta*, HIRASE, *Coll. Japan. Shells*, p. 27, pl. 48, fig. 5.

1952. *Siliqua alta*, HABE, *Gen. Japan. Shells, Pelec.*, p. 230, figs. 583–585.

1955. *Siliqua alta*, HABE, *Publ. Akkeshi Mar. Biol. Stat., no. 4*, p. 20, pl. 6, figs. 13, 14.

1959. *Siliqua alta*, KIRA, *Colour. Ill. Shells, Japan*, p. 162, pl. 61, fig. 14.

1959. *Siliqua alta*, MAKIYAMA, *Pal. Soc. Japan, Spec. Pap., no. 5*, pl. 70, figs. 3–5.

Remarks: Only one poorly preserved specimen of left valve was obtained. The specific determination is based mainly on relatively high shell and broad and prominent internal ridge which run nearly vertically or slightly inclined posteriorly to the poster-dorsal margin. Acute angle between the internal ridge and the postero-dorsal margin is one of the most remarkable characters of the species.

Recent form of *Siliqua alta* has hitherto been reported restrictedly from north of Hokkaido in western Pacific.

Measurements: Length 24.4 mm, height 12.1, thickness 3.0, Reg. No. CM 8756.

Occurrences: *Spisula-Clinocardium* community. Loc. 6; a separate small left valve, posterior end broken.

Genus *Solen* LINNÉ, 1758

Solen krusensterni SCHRENCK

Plate 3, figure 4.

1867. *Solen krusensternii* SCHRENCK, *Reisen u. Forsch. Amurlande, vol. 2*, p. 594, pl. 25, figs. 9–12.

1906. *Solen krusensternii*, TOKUNAGA, *Jour. Coll. Sci., Imp. Univ. Tokyo, vol. 21, art. 2*, p. 36, pl. 2, fig. 19.

1922. *Solen krusensternii*, YOKOYAMA, *ibid., vol. 44, art. 1*, pp. 134–135, pl. 9, fig. 5.

1934. *Solen krusensterni*, KINOSHITA and ISAHAYA, *Rep. Fish. Surv., Hokkaido Fish. Exper. Stat., no. 33*, p. 17, pl. 14, fig. 99.

1952. *Solen stricta* GOULD, HABE, *Gen. Japan. Shells, Pelec.*, p. 232, figs. 594, 595.

1954. *Solen krusensterni*, TAKI and OYAMA, *Pal. Soc. Japan, Spec. Pap., no. 2*, pl. 29, fig. 5.

1955. *Solen krusensterni*, HABE, *Publ. Akkeshi Mar. Biol. Stat., no. 4*, p. 20, pl. 6, figs. 1, 2.

1959. *Solen (Solenarius) krusensterni*, YAMAMOTO and HABE, *Bull. Mar. Biol. Stat. Asamushi, vol. 9, no. 3*, p. 109, pl. 11, fig. 7.

Remarks: The specimens are undoubtedly identical with *S. krusensterni* SCHRENCK by their relatively higher shell, straight or weakly concave dorsal margin, and rounded posterior margin. This species is common in upper shelf of North Japan and Sakhalien.

Measurements (in mm):

Specimen	Reg. No.	Locality	Valve	Length	Height	Thickness	Ratio of H/L	T/H
1	CM 8757	Loc. 1	R	ca78	18.5	5.5	0.24	0.3
2	CM 8758	//	//	55.7	12.8	4.3	0.23	0.33

Occurrences: *Mercenaria-Peronidia* community (Exclusive species). Loc. 1; common, well preserved, common size, fragmental specimens rich. Loc. 2; abundant, but mostly broken specimens. Loc. 3; few, large but broken specimens. A poorly preserved specimen was found from Loc. 6.

Family Hiatellidae

Genus *Panope* MÉNARD, 1807

Panope cf. *estrellana* (CONRAD)

Plate 3, figures 2, 3.

1910. *Panope estrellana* (CONRAD), ARNOLD, *U.S. Geol. Surv. Bull., no. 396*, p. 64, pl. 15, fig. 1.
1938. *Panope japonica* A. ADAMS, NOMURA, *Sci. Rep., Tohoku Imp. Univ., ser. 2, vol. 19, no. 2*, p. 268, pl. 36, figs. 7a, 7b.

Description: Shell rather small for the genus, almost equivalve, inequilateral, beak situated about anterior 1/3 to 2/5 of shell length. Anterior margin evenly rounded; posterior margin truncated, broad; postero-dorsal margin concave, postero-dorsal shoulder expanded; ventral margin gently arcuated. Surface wavy. Posterior end broadly gaping.

Remarks: The specimens closely resemble *P. estrellana* illustrated by ARNOLD (1910) in shell size and outline, and the writer could not find any distinction between them. The specimens are characterized by anteriorly situated beak and swelled postero-dorsal end. They can be distinguished from *Panope japonica* A. ADAMS by more slender shell and by above-mentioned characters.

The writer once regarded them as a subspecific form of *Panope japonica*, although, no decisive data was obtained. But now, he compares the present form with *P. estrellana* (CONRAD) tentatively.

"*Panope japonica*", reported by NOMURA from the Pliocene Tatunokuti formation of Sendai district, Northeast Japan, may be a same form as the present specimens. It is also found from the upper Miocene Shigarami formation of Central Japan, having been reported by YOKOYAMA (1925, p. 10) as *Panope generosa* (GOULD). *Panope rhomboidea* HIRAYAMA (1955) reported from the Asagai formation of the Joban coal field is an allied species. This can be separated from the present form by much more elongated and small shell.

Measurements (in mm):

Specimen	Reg. No.	Locality	Valve	Length	Height	Thickness	Position of beak from anterior
1	CM 8763	Loc. 1	conj.	79.0	47.6	30.6+	26.2
2	CM 8764	"	L	79.3	53.2	16.0	34.8
3	CM 8765	"	"	67.4	37.1	12.7	27.7
4	CM 8766	"	R	78.6	42.5	14.8	30.6
5	CM 8767	"	"	ca110	63.3	21.5	ca50
6	CM 8769	Loc. 2	L	71.6	40.7	13.0	26.2

Occurrences: *Mercenaria-Peronidia* community (exclusive species). Loc. 1; abundant, perfectly preserved, some specimens are conjoined valves, shell large. Loc. 2; few, complete and fragmental specimens, large. The present species decreases in individual number from Loc. 1 to Loc. 2. A small broken specimen was found in Loc. 6.

Family Myacidae

Genus *Mya* Linné, 1758

Mya japonica Jay

1857. *Mya japonica* Jay, *Rep. Shells Coll. Japan Exped., Comm. Perry, vol. 2*, p. 292, pl. 1, figs. 7, 10.

1926b. *Mya arenaria* Linné, Yokoyama, *Jour. Fac. Sci., Imp. Univ. Tokyo, vol. 1, pt. 7*, p. 241, pl. 30, fig. 1.

1931. *Mya japonica*, Kuroda, *Geol. Middle Shinano, pt. 4*, pp. 64–65, pl. 8, fig. 55, pl. 9, figs. 57, 58.

1955. *Mya (Arenomya) japonica*, Habe, *Publ. Akkeshi Mar. Biol. Stat., no. 4*, pp. 22–23, pl. 7, fig. 12.

1957. *Mya (Arenomya) (arenaria* var.) *japonica*, Ozaki, Fukuta and Ando, *Bull. Nat. Sci. Mus., vol. 3, no. 3*, p. 174, pl. 33, figs. 48a, 48b.

1957. *Mya japonica*, Fujie, *Jour. Fac. Sci., Hokkaido Univ., Ser. 4, vol. 9, no. 4*, pp. 406–409, pl. 1, figs. 1–5,

1958. *Mya japonica*, Makiyama, *Pal. Soc. Japan, Spec. Pap., no. 4*, pl. 41, fig. 1.

1959. *Mya (Arenomya) japonica*, Yamamoto and Habe, *Bull. Mar. Biol. Stat. Asamushi, vol. 9, no. 3*, p. 113, pl. 12, fig. 24.

Remarks: Fujie (1957) concluded that the distribution of *Mya japonica* Jay may be limited mainly to Hokkaido, Sakhalien and Kurile Islands.

Reg. No.: CM 8772, CM 8773.

Occurrences: A few specimens are known in this faunule. *Spisula-Clinocardium* community (Loc. 6; two large specimens, one is broken) and *Patinopecten* community (Loc. 9, fragmental specimens). Separation of contained community between this species and *Mya japonica oonogai* Makiyama is a noteworthy fact.

Mya japonica oonogai Makiyama

Plate 3, figure 13.

1925a. *Mya arenaria* Linné var. *japonica* Jay, Yokoyama, *Jour. Coll. Sci., Imp. Univ. Tokyo, vol. 45, art. 5*, pp. 16–17, pl. 6, fig. 4.

1925c. *Mya arenaria* Linné var. *japonica*, Yokoyama, *Jour. Fac. Sci., Imp. Univ. Tokyo, sec. 2, vol. 1, pt. 1*, p. 10, pl. 3, fig. 3.

1935. *Mya oönogai* Makiyama, *Warera no Kobutsu, vol. 4, no. 3*, pp. 37–38, fig. O.

1951. *Mya (Arenomya) (arenaria* var.) *japonica*, Habe, *Ill. Cat. Japan. Shells, vol. 1, no. 12*, p. 74, pl. 12, fig. 9.

1952. *Mya (Arenomya) japonica*, Habe, *Gen. Japan. Shells, Pelec.*, p. 237, fig. 612.

1955. *Mya (Arenomya) japonica oonogai*, Habe, *Publ. Akkeshi Mar. Biol. Stat., no. 4*, p. 23, pl. 6, fig. 3.

1957. *Mya japonica oonogai*, Fujie, *Jour. Fac. Sci., Hokkaido Univ., ser. 4, vol. 9, no. 4*, pp. 403–406.

1957. *Mya japonica*, Tsuchi, *Rep. Lib. Arts Fac., Shizuoka Univ., Nat. Sci., vol. 2, no. 1*,

tab. 1, fig. 25.

1959. *Mya (Arenomya) japonica*, KIRA, *Colour. Ill. Shells, Japan*, pp. 163-164, pl. 61, fig. 22.

Remarks: The subspecies *oonogai* differs from the preceeding *Mya japonica* in lower shell and more slender anterior part. In the faunule the two forms, *japonica* and *j. oonogai*, are found respectively from different communities.

Reg. No.: CM 8774, CM 8775.

Occurrences: *Turritella-Mya* community (exclusive and dominant species). Loc. 8; abundant, preserved in living state standing almost vertically to stratification, shell not large.

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K. Chinzei

Molluscan Fauna of the Pliocene Sannohe Group of Northeast Honshu, Japan

II.   The Faunule of the Togawa Formation

Plate I

Explanation of Plate I

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Molluscan Fauna of the Pliocene Sannohe Group of Northeast Honshu, Japan

II.   The Faunule of the Togawa Formation

Plate II

Explanation of Plate II

K. CHINZEI

Molluscan Fauna of the Pliocene Sannohe Group of Northeast Honshu, Japan

II. The Faunule of the Togawa Formation

Plate III

Explanation of Plate III

K. Chinzei

Molluscan Fauna of the Pliocene Sannohe Group of Northeast Honshu, Japan

II.   The Faunule of the Togawa Formation

Plate IV

Explanation of Plate IV

CONTACT METASOMATIC IRON AND COPPER ORE DEPOSITS OF THE KAMAISHI MINING DISTRICT, NORTHEASTERN JAPAN

By

Akio Tsusue

Contents

chalcopyrite. The writer prefers to call it "massive cubanite" in order to distinguish it from lamellar cubanite. Two or three sets of pentlandite blades, and pentlandite-bearing pyrrhotite blades are usually observed in massive cubanite. From the para-genesis of minerals constituting ores and their textures, massive cubanite is thought to have been formed as follows: the paragenesis of nickel-bearing chalcopyrite solid solution, nickeliferous and ferriferous cubanite solid solution, and nickel-bearing pyrrhotite solid solution was stable during the formation of ores, but, with a fall of temperature, the unmixing of the nickeliferous and ferriferous cubanite solid solution took place and the solid solution was split into massive cubanite, pyrrhotite, and pentlandite.

From the porphyrite-side to the marble-side, the following zonal distribution of ores is observed in the Second Copper ore body: 1) magnetite replacing garnet-pyroxene skarn or dark green pyroxene skarn; 2) chalcopyrite and pyrrhotite replac-ing dark green pyroxene skarn; and 3) chalcopyrite, massive cubanite, and pyrrhotite replacing dark green pyroxene skarn. This zonal distribution of ores may have been due to a decrease in mobility of oxygen and iron during the formation of ores, namely the chemical potential gradients of oxygen and iron may have been formed in zoned skarns during the formation of ores. Threfore, magnetite may have been formed in a place where the chemical potential of oxygen was high, whereas, sulphide ore with high iron content may have been formed where the chemical potential of oxygen was low and that of iron was high.

I. Introduction

Since the eminent work contributed by LINDGREN and GOLDSCHMIDT, much study has been given to the genesis of contact metasomatic ore deposits in many countries. However, the theoretical study in this field began with the work of KORZHINSKY.

The present paper undertakes to describe the mode of occurrence of skarns, paigeite rock, and ores found in the Kamaishi mining district, and to describe the parageneses of minerals of these rocks, and moreover, to clarify contact-reaction-metasomatic phenomena during the formation of skarns and metasomatic phenomena during the formation of paigeite rock and ores. In particular, the writer discusses in detail the formation of parageneses of ludwigite and paigeite, "massive cubanite", and the zonal distribution of ores.

Kamaishi mine

The Kamaishi mine is located in the northeastern part of Japan, about 20 kilometers west of the Kamaishi harbor, approximately at longitude E141°41′ and latitude N39°18′. The location of the Kamaishi mining district is shown in Fig. 1.

The opening of the mine is said to have taken place early in the Seven-teenth Century, however, the mine has only been actively operated from the later Nineteenth Century. Today, the mine is under the direction of the Nittetsu Mining Co. Ltd..

The iron and copper concentrates produced from the mine up to 1957 amounted to about 13,000,000 and 70,000 tons respectively. The iron tenor of

the former ranged from 51 to 59 per cent, and the copper tenor of the latter ranged from 15 to 18 per cent. The tenor of iron crude ore ranged from 30 to 35 per cent, and that of copper crude ore ranged from 1 to 2 per cent. In 1957, about 350,000 tons of iron concentrate and about 20,000 tons of copper concentrate were produced from this mine.

Previous works

As the Kamaishi mining district has been the scene of active iron mining operations for a century, geologic surveys for mineral resources have frequently been carried out by many geologists. Chief contributions to the geology of the mining district are given below.

YAMANE (1923) made a geologic survey of the district and clarified the succession of intrusive rocks. Furthermore, he outlined the ore deposits of this district.

TAKEDA (1950) descibed the mode of occurrence of skarns and ores forming the Sahinai ore deposit.

Fig. 1. Index map showing the location of the Kamaishi mining district.

TAKEUCHI, NAMBU, and WADA (1952) described the mode of occurrence of skarns and ores found in the Ômine mine.

WATANABE (1953) stated the genesis of contact metasomatic iron ore deposits in Japan and referred to those of this district.

ONUKI (1956), MORIAI (1957) and ONUKI and MORIAI (1959) studied the geology and sedimentary rocks of the district and clarified the age of the sedimentary rocks. Moreover, they outlined the geologic structure of the district.

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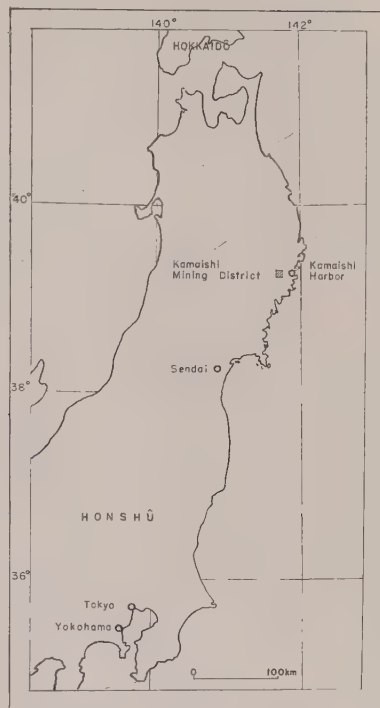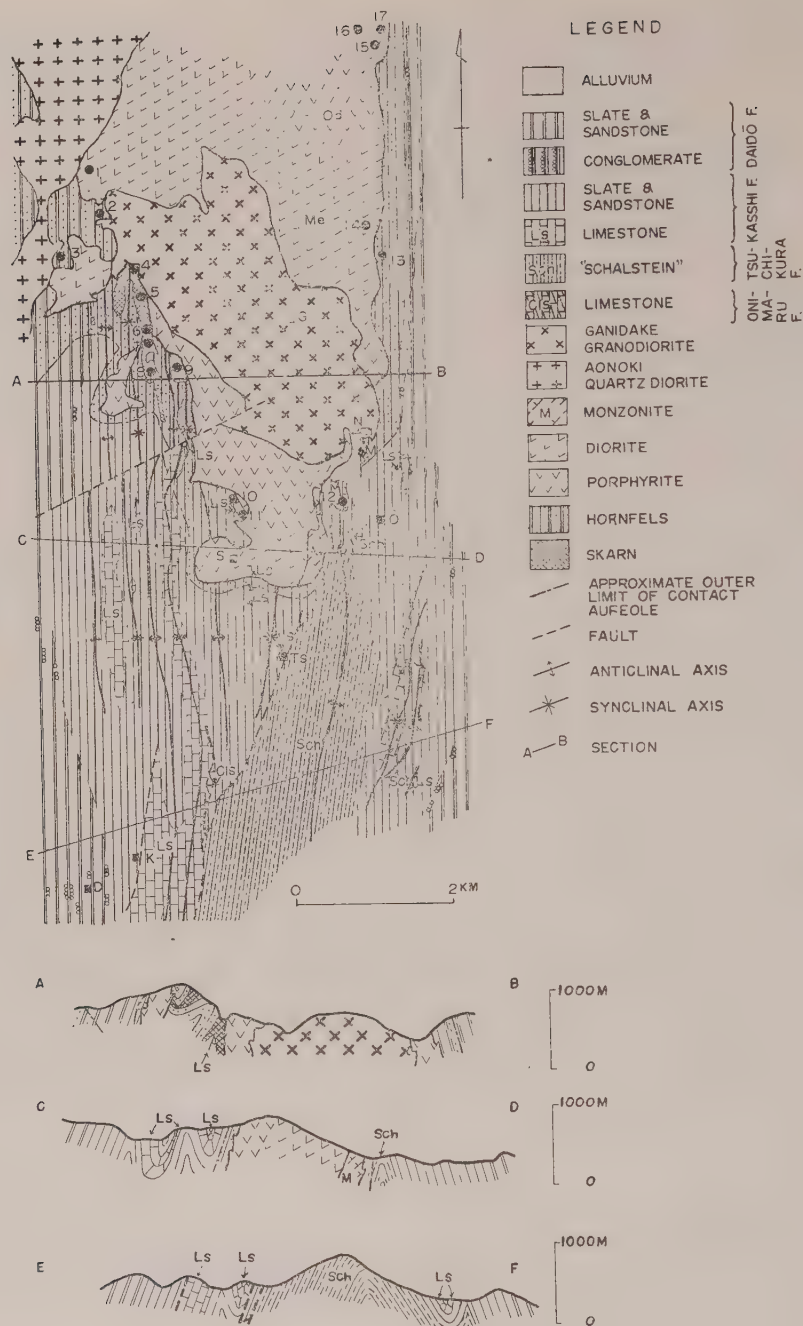
Fig. 2. Geologic map of the Kamaishi mining district.

●—Contact metasomatic ore deposits in the mining district, 1–Aonoki ore
    deposit, 2–Ômine ore deposit, 3–Ômine mine, 4–Akaiwa ore deposit,
    5–Sahinai ore deposit, 6–Aoban ore deposit, 7–Motoyama ore deposit,
    8–Tengumori ore dep sit, 9–Shinyama ore deposit, 10–Daisen ore deposit,
    11–Nozoki ore deposit, 12–Maeyama ore deposit, 13–Hosogoe ore deposit,
    14–Medake ore deposit, 15–Odake ore deposit, 16–Takamae ore deposit,
    17–Kabayama ore deposit.
△—Od–Mt. Odake, Mc–Mt. Medake, G–Mt. Ganidake.
■—N–Nakanosawa dam, Ô–Ôhashi Station, S–Sennin Pass, Ts–Tsuchikura
    Pass, K–Kamiarisu Station, D–Daidô village.

II. Outline of geologic feature of the Kamaishi mining district

This mining district is occupied by sediments of Paleozoic age, various kinds of intrusives of probable Cretaceous age, and contact metamorphosed rocks derived from the sediments (Fig. 2). The sediments show a repeated synclinal-anticlinal structure on a minor scale, and form a large anticlinal structure as a whole. Intrusives, such as diorite, porphyrite, quartz diorite, and granodiorite cut discordantly the folded sedimentary rocks. Because of these intrusions, the sedimentary rocks were extensively metamorphosed.

In order to clarify the geologic setting of contact metasomatic ore deposits in this district, sedimentary, intrusive and contact metamorphosed rocks will be briefly described in this chapter.

Paleozoic sedimentary rocks

The sedimentary rocks in this district range from Carboniferous to Permian in age and are chiefly limestone, "schalstein", and slate, but include some sandstone and conglomerate. These sediments have been named and divided into the Onimaru, Tsuchikura, Kasshi, and Daidô formations by ONUKI (1956), and ONUKI and MORIAI (1959). The columnar section of the sediments is diagramatically shown in Fig. 3. There appears to be no unconformity in the whole Permian column. However, the Onimaru formation of Carboniferous age is brought into contact with the Kasshi formation of Permian age by thrusts.

These formations have been correlated with those of type localities in the southern part of the Kitakami mountainland by ONUKI (1956).

Onimaru formation

The formation crops out 1.5 kilometers northwest of Kamiarisu Station*, and is made up of black massive limestone. The thickness of the formation is about 30 meters. The limestone is brought into contact with black phyllitic slate and massive limestone of the Kasshi formation by thrusts that strike N10°E and dip steeply westward.

ONUKI and MORIAI (1959) reported that the limestone contains index fossils

* Names of locality cited in the text are shown in Fig. 2.

AGE		FORMATION	COLUMNAR SECTION	LITHOLOGY	THICKNESS IN METERS
PALEOZOIC	PERMIAN	DAIDÔ F.		BLACK MASSIVE SLATE	800+
				BLACK MASSIVE SLATE INTERCALATED WITH SANDSTONE AND "USU-GINU" CONGLOMERATE	
		KASSHI F.		BLACK MASSIVE SLATE CONTAINING A FEW CALCAREOUS LENSES	500-
				MASSIVE LIMESTONE CONTAINING A FEW ARGILLACEOUS LENSES	1000
				BLACK PHYLLITIC SLATE	
		TSUCHIKURA F.		"SCHALSTEIN" CONTAINING A FEW ARGILLACEOUS LENSES	600+
				"SCHALSTEIN"	
	CARBONIFEROUS-?	?——FAULT—— ONIMARU F. ——FAULT—		BLACK MASSIVE LIMESTONE	30+

Fig. 3.　Diagramatic columnar section of the Kamaishi mining district.

of Carboniferous age.

Tsuchikura formation

The formation occurs near the ridge extending southward from the Tsuchikura Pass, and converges to a point 0.6 kilometer of Ôhashi Station. It is made up largely of green phyllitic tuff, green massive lava, and a small amount of tuff breccia. The composition of these rocks ranges from rhyolitic andesite to basaltic andesite. However, the rocks are not separated and are lumped under the name of "schalstein" in the accompanying geologic map (Fig. 2).

There appears to be no lower limit to the formation in this district. In the upper part of the formation, "schalstein" contains a few argillaceous lenses. Where the observable thickness of the formation is greatest it is 500 meters. The strike of the beds in the formation ranges from N20°E to N30° W, and they have a steep easterly dip in the eastern part and a steep westerly dip in the western part. Therefore, it may be concluded that the Tsuchikura formation forms an anticline plunging gently into north, consideration being also given to paleontologic data of the Kasshi formation. The writer calls this structure "the Tsuchikura anticline" in order to distinguish it from other anticlines in the same district.

In the western limb of the Tsuchikura anticline, "schalstein" of the Tsuchikura formation comes partly into contact with black phyllitic slate of the Kasshi formation by a normal fault striking N20°-30°E and dipping steeply westward.

No fossils have been found in the formation.

Kasshi formation

The Kasshi formation rests conformably on the Tsuchikura formation, and constitutes the eastern and western limbs of the Tsuchikura anticline. The Kasshi formation in the limbs is also found to have been extensively folded. Axes of minor foldings are approximately parallel to that of the Tsuchikura anticline. The eastern limb of the formation is developed from the southern part of Ôhashi Station to the vicinity of the Takamae ore deposit. Also, the western limb is developed from the southern part of Kamiarisu Station to the Akaiwa ore deposit.

In the eastern limb the lowest part of the formation is composed of black phyllitic slate. The sediment overlying the slate is white or gray limestone with well-marked banded structure. The limestone consists mainly of medium- and fine-grained calcite with extremely small amounts of impurities, such as quartz and pyrite. The banded structure is due to the abrupt variation in grain size of calcite. Where the thickness of the limestone bed is greatest it is 80 meters. However, the bed is missing in many sections. The upper part of the formation consists of black massive slate. The thickness of the formation in the eastern limb is about 500 meters. The strike of sediments in the limb ranges from N20°E to N20°W, and the sediments have a steep westerly dip.

TAKEDA (1950) reported that calcareous slate near Ôhashi Station contains an index fossil of Permian age.

In the western limb the lowest part of the formation consists of black phyllitic slate. The sediment overlying the slate is white or gray massive limestone containing a few argillaceous lenses. The limestone is composed chiefly of medium- or fine-grained calcite with extremely small amounts of impurities, such as quartz, hematite, and pyrite. Where the thickness of the limestone bed is greatest it is 300 meters. The upper part of the formation is made up of black massive slate containing a few calcareous lenses, the maximum thickness of the formation in the western limb being 1500 meters. The strike of sediments in the limb ranges from N30°E to N10°W, and the sediments have a steep easterly or westerly dip.

ONUKI (1956) reported that limestones in the western limb contain index fossils of Permian age.

Daidô formation

The Daidô formation rests conformably on the Kasshi formation, and also constitutes the eastern and western limbs of the Tsuchikura anticline. The eastern limb of the formation is developed from the southern part of Ôhashi Station to the vicinity of the Takamae ore deposit, and the western limb is developed from the Daidô village to the Ômine mine.

In the eastern limb the lower part of the formation is composed of black massive slate intercalated with sandstone and conglomerate. Pebbles of the conglomerate are chert and slate, and the matrix is sandstone. The upper part of the formation is made up of black massive slate. An upper limit to

the formation is not known in this district. The strike of sediments in the eastern limb ranges from N20°E to N10°W and they have a steep easterly dip.

In the western limb the lower part of the formation consists of black massive slate intercalated with sandstone, the "Usuginu" conglomerate, and a small amount of limestone. Boulders of the conglomerate are granite, chert, and slate, and the matrix is sandstone. The upper part is made up of black massive slate. The sediments in the western limb have a north strike and a steep westly dip.

ONUKI (1956) and MORIAI (1957) reported that thin limestone lenses in the western limb contain index fossils of Permian age.

Intrusive rocks

Intrusive rocks found in the district are mostly granodiorite, quartz diorite, diorite, and porphyrite, but include some monzonite, pegmatite, aplite, and lamprophyre.

The succession of intrusive rocks is shown in Table 1, in which arrows indicate the transection relation between two rocks and dots indicate the transitional relation between two rocks established by actual contact. The successive intrusion of these rocks may have occurred in Cretaceous age. Main points of importance with regard to the age of igneous activity may be summarized as follows: 1) According to HANZAWA (1954), the pre-Cretaceous sedimentary rocks in the Kitakami mountainland were chiefly folded during the orogenesis of the Ôshima phase named by KOBAYASHI. 2) Intrusive rocks in the district cut discordantly the folded structure of sedimentary rocks of Permian age as indicated in Fig. 2, and no effect of crushing nor sign of cataclastic effect is observed in the intrusive rocks. 3) The Ganigake granodiorite and Aonoki quartz diorite resemble petrographically granodiorites of the Miyako type developed near the town of Miyako which is about 50 kilometers north of this district. According to ISHII et al. (1953), the intrusion of the granodiorites took place in early Cretaceous age. 4) Generally speaking, dikes or veins of aplite, pegmatite, and lamprophyre are frequently associated with granitic or granodioritic intrusives.

Table 1. Succession of intrusive rocks in the Kamaishi mining district.

Diorite

The rock occurs as large irregular masses in the neighborhood of the Sennin Pass, the Sahinai ore deposit, the Ômine mine and Mount Medake. The diorite gradates into porphyrite at the Nakanosawa dam. Also, the

Ganidake granodiorite penetrates into diorite along its joints in the Sahinai ore deposit. In the vicinity of the Aonoki ore deposit, the Aonoki quartz diorite penetrates into diorite along its joints. The diorite is extensively skarnized in the Sahinai ore deposit.

Megascopically the rock is dark gray. Under the microscope it is seen to be hypidiomorphic-granular in texture and to be composed mainly of euhedral plagioclase and subhedral or anhedral quartz, amphibole, and biotite. The average grain size is about 1 millimeter. Plagioclase (50 per cent)* is prismatic and shows polysynthetic twinning and normal zoning with cores of An_{60} and margins of An_{45}. Quartz (9 per cent) is interstitial. Amphibole (25 per cent) is pleochroic from pale yellow to light green. Biotite (13 per cent) is also pleochroic from pale yellow to dark brown and is partly altered to chlorite. As accessory minerals (3 per cent), apatite, sphene, magnetite, and ilmenite are common.

Porphyrite

The rock is found as irregular masses in the Shinyama ore deposit and in the vicinity of the Sennin Pass, the peak 0.5 kilometer west of the Tengu-mori ore deposit, the Nakanosawa dam, and Mount Odake. The Ganidake granodiorite penetrates into the porphyrite along its joints in the vicinity of the Shinyama ore deposit. The porphyrite is extensively skarnized in the Shinyama ore deposit.

Megascopically the rock varies from dark gray to dark brownish gray and is porphyritic. Under the microscope it is seen to be hollocrystalline. Plagioclase (9 per cent) and amphibole (9 per cent) occur as phenocrysts reaching 2 millimeters in length. These phenocrysts are set in a fine-grained groundmass made up of plagiocase (20 per cent), amphibole (34 per cent, biotite (16 per cent) with a small amount of quartz (7 per cent). The plagio-clase of both phenocrysts and the groundmass is prismatic and shows normal zoning and polysynthetic twinning. The mineral is slightly altered to epidote and sericite. The amphibole of both phenocrysts and the groundmass shows distinct pleochroism: X= pale yellow, Y= greenish yellow, Z= light green. Biotite forms small flakes. The pleochroic scheme of biotite is: X= pale yellow, Y & Z= pale greenish brown. Interstitial spaces of above minerals are commonly filled up with quartz. Apatite, sphene, magnetite, and ilmenite are the accessory constituents (5 per cent).

Ganidake granodiorite

A granodioritic mass occurs in the central part of the district. The mass is mapped as the Ganidake granodiorite in the accompanying geologic map (Fig. 2). From its mineralogical composition, however, granodiorite occurs in the central part of the mass and quartz diorite in the marginal part. The granodiorite and quartz diorite appear to gradate into each other, at least, no evidence of successive intrusions has been found. The central area is general-

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* Modal percentage representing the average composition of typical rock types in this district.

ly homogeneous, but in the marginal area, a banded structure due to the planar arrangement of mafic minerals is observed and basic inclusions become abundant. The marginal area is slightly or extensively skarnized near the Shinyama and Sahinai ore deposits.

Microscopically the texture of the granodiorite and quartz diorite is hypidiomorphic-granular and they are composed mainly of plagioclase, potash feldspar, quartz, amphibole, and biotite. The average grain size is about 2 millimeters. Plagioclase (46 per cent, 54 per cent)* is prismatic and more or less euhedral against potash feldspar and quartz. Plagioclase frequently shows polysynthetic twinning and normal zoning. The chemical composition of the mineral in the granodiorite changes gradually from An_{55} in cores to An_{30} in rims. But from An_{50} to An_{35} in the case of the quartz diorite. The plagiclase is slightly altered to sericite and epidote. Potash feldspar (17 per cent, 3 per cent) occurs in interstitial spaces of plagioclase and often encloses idiomorphic plagioclase and mafic minerals. Potash feldspar is usually finely microperthitic and the thickness of lamellae is a few microns. It seems to be mostly microcline. Usually a wavy or indistinct grid can be made out under crossed nicols and often the familiar microcline grid is clear and sharp. The "secondary" plagioclase defined by Tuttle (1951) is not observed at the boundary between potash and plagioclase feldspars in this granodioritic mass. Quartz, (26 per cent, 26 per cent), much of which is interstitial, has numerous inclusions and often encloses idiomorphic plagioclase and mafic minerals. The pleochroic scheme of amphibole (3 per cent, 2 per cent) is: X= pale yellow, Y= pale yellowish green, Z= green. Optical character is negative and the 2V is large. Biotite (7 per cent, 10 per cent) is more abundant in amount than amphibole, and has a brownish tint with distinct pleochroism: X= pale yellow, Y & Z= brown. $2V=0^0$. Chlorite is frequently found as an alteration product of biotite. As accessory minerals (1 per cent, 5 per cent), apatite, sphene, magnetite, ilmenite, hematite, chalcopyrite, and cubanite are present.

<center>Aonoki quartz diorite</center>

Near the Aonoki ore deposit quartz dioritic rock occurs as a large irregular mass. The marginal part of the mass is slightly skarnized in the Ômine mine.

Megascopically the rock is gray. Under the microscope it is observed to be hypidiomorphic-granular in texture and to consist mainly of plagioclase, quartz, amphibole, biotite, and a small amount of potash feldspar. The average grain size is about 3 millimeters. Plagioclase (50 per cent) is subhedral or euhedral against quartz, and slightly decomposed into sericite. The composition of plagioclase was estimated at An_{35}–An_{50}. Zonal structure and polysynthetic twinning are very common. Quartz (10 per cent) and potash feldspar (5 per cent) occur in interstitial spaces of plagioclase and mafic minerals. Potash feldspar seems to be mostly microcline. Quartz frequently

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* The former modal percentage is that of granodorite, and the latter percentage is that of quartz diorite.

includes plagioclase and mafic minerals. Chlorite is often found closely associated with amphibole (19 per cent) and biotite (14 per cent). As accessory minerals (2 per cent), apatite, sphene, ilmenite, magnetite, and hematite are common.

Monzonite

Small masses of monzonite crop out on the eastern slope of the Sennin Pass and near the Nakanosawa dam. The rock is seen to gradate into the Ganidake granodiorite near the Nakanosawa dam.

Megascopically the rock is dark gray. Microscopically the rock is made up largely of plagioclase, potash feldspar, clinopyroxene, amphibole, biotite with a small amount of quartz. The average grain size is about 2 millimeters. Plagioclase (35 per cent) is prismatic and displays polysynthetic twinning and normal zoning with cores of An_{30} and margins of An_{45}. The mineral is partly altered to sericite and epidote. Potash feldspar (27 per cent) occurs in interstitial spaces of plagioclase, and often encloses idiomorphic plagioclase. Potash feldspar is usually finely microperthitic and seems to be mostly microcline. Quartz (5 per cent) fills the interstices of the other minerals. Clinopyroxene (3 per cent) is usually surrounded by amphibole or biotite corona. Amphibole (14 per cent) is pleochroic from pale yellow to light green. Biotite (12 per cent) is also pleochroic from pale yellow to dark brown. Amphibole and biotite are often decomposed into chlorite. As accessory minerals (4 per cent), apatite, sphene, magnetite, and ilmenite are common.

Later porphyrite

Several porphyrite dikes intruding the Ganidake granodiorite, the porphyrite of earlier intrusion, and contact metamorphosed rock are found in the district. The dikes were named "the Later porphyrite" by YAMANE (1923) in order to distinguish them from the porphyrite of earlier intrusion. The dikes range from 0.1 to 20 meters in width. The strike ranges from N40°E to N 70°E or from N40°W to N80°W and the dip is almost vertical. The Later porphyrite includes fragments of granodiorite in the Akaiwa ore deposit, and is cut by aplitic veins near the Nakanosawa dam. The Later porphyrite is slightly or extensively skarnized near the Shinyama and Sahinai ore deposits.

Megascopically the rock is light greenish gray and porphyritic. Under the microscope, the rock is hollocrystalline. Plagioclase (10 per cent) and amphibole (5 per cent) occur as phenocrysts reaching 2 millimeters in length. These phenocrysts are in a fine-grained groundmass made up of plagioclase (30 per cent), amphibole (25 per cent) with small amounts of biotite (15 per cent) and quartz (10 per cent). Apatite, sphene, ilmenite, and magnetite are accessory constituents (5 per cent).

Lamprophyre

Several lamprophyre dikes intruding the Ganidake granodiorite, the porphyrite of earlier intrusion, diorite, contact metamorphosed rock, skarn, and ore are found in the district. The dikes range from 0.1 to 10 meters in width. Their strikes range from N40°E to EW and their dips range from 50°SE to vertical. The rock is free from skarnization.

Megascopically the rock is black. Under the microscope it is hollocrysta-
line and porphyritic. Phenocrysts of the rock are euhedral or subhedral
crystals of amphibole which are locally associated with a small amount of
biotite. The groundmass consists mostly of fine-grained plagioclase, amphi-
bole, and a small amount of biotite. In this rock mafic minerals make up
more than one-third of the composition. As accessory minerals, carbonate,
apatite, sphene, ilmenite, and magnetite are present.

Pegmatite and aplite

Several pegmatite veins or dikes cutting diorite, skarn, and magnetite ore
are found in the Aonoki ore deposit. The veins and dikes range from 0.1 to
2 meters in width. The strike and dip are various. The pegmatites consist
mainly of quartz, potash feldspar with small amounts of plagioclase, mica,
amphibole, sphene, zircon, and apatite.

Aplite veins cutting the Ganidake granodiorite and the Later porphyrite
are found near the Nakanosawa dam. The aplites are free from skarnization
and consist of quartz and small amounts of potash feldspar and plagioclase.

Contact metamorphosed rocks

Because of the intrusions of the igneous rocks, the sedimentary rocks
were extensively metamorphosed. The approximate outer limit of the contact
aureole is shown in the accompanying geologic map (Fig. 2). The aureole is
characterized by the megascopic presence of biotite in the hornfels derived
from argillaceous rock. Dimensions of the contact aureole around diorite and
porphyrite appear to be smaller than those of the Ganidake granodiorite and
Aonoki quartz diorite. The occurrence of the main contact metamorphosed
rocks will be mentioned here.

Cordierite hornfels

No cordierite hornfelses have been observed in contact aureoles of diorite,
porphyrite, and the Ganidake granodiorite. In the vicinity of the Aonoki
quartz diorite, the belt of cordierite hornfels is exposed. It is a fine-grained
dark brown hornfels. Under the microscope it is seen to be totally recon-
structed. Cordierite up to 0.5 millimeter in diameter occurs almost exclusively
as porphyroblasts. The mineral shows characteristic sector twinning and is
comparatively free from inclusions, such as magnetite and biotite. These
porphyroblasts are set in a fine-grained groundmass made up of plagioclase
of the composition of andesine, quartz, and biotite. Plagioclase forms un-
twinned xenoblastic grains. Biotite is strongly pleochroic in red-brown tints.
The remaining minerals are magnetite and pleochroic grains of tourmaline.

Biotite hornfels

In the neighborhood of diorite, porphyrite, monzonite, the Ganidake grano-
diorite, and Aonoki quartz diorite, belts of biotite hornfels are exposed. It is
a fine-grained brownish gray hornfels in which flakes of biotite are readily
recognized. In thin section it is seen as an equigranular hornfels made up
of plagioclase of the composition of andesine, potash feldspar, quartz, amphi-
bole, and biotite in red-brown flakes. The pleochroic scheme of amphibole is

X= pale yellowish green, Y= pale green, Z= pale green. Magnetite is an accessory constituent.

<div align="center">Marble</div>

In the contact aureole marble consists mostly of intricately twinned calcite, but minute amphibole is present along the grain boundaries of the calcite.

Geologic structure

As stated before sedimentary rocks in the district show a repeated synclinal-anticlinal structure on a minor scale, and they form a large anticlinal structure as a whole. Axes of the minor folds are parallel to that of the major fold and they pitch gently northward or are almost horizontal. The sedimentary rocks may have been folded during the orogenesis of the Ôshima phase of Cretaceous age as stated by HANZAWA (1954).

The faults cutting sedimentary and igneous rocks consist of two groups, namely of N–S direction, and of NEE–SWW and NWW–SEE directions. The faults extending with their strikes in N–S direction may have been formed during the orogenesis. The faults in NEE–SWW and NWW–SEE directions may have been formed after the Ganidake granodiorite had solidified. Intrusive rocks, such as the Later porphyrite and lamprophyre are found as dikes along these faults of the second group.

Geologic history

Summarizing the facts described above, the geologic history of this district is given below.

1) Deposition of Onimaru formation—Carboniferous
—(The historic record between the deposition of the Onimaru formation and that of the Tsuchikura formation remains uncertain.)—
2) Deposition of Tsuchikura formation—Permian
3) Deposition of Kasshi formation—Permian
4) Deposition of Daidô formation—Permian
5) Folding and faulting of the formations—Cretaceous (?)
6) Intrusions of porphyrite and diorite, and contact metamorphism of the formations—Cretaceous (?)
7) Intrusions of Ganidake granodiorite, monzonite, and Aonoki quartz diorite, and contact metamorphism of the formations—Cretaceous (?)
8) Faulting of above-mentioned formations and intrusive rocks—Cretaceous (?)
9) Intrusion of Later porphyrite—Cretaceous (?)
10) Intrusions of lamprophyre, pegmatite, and aplite—Cretaceous (?)

<div align="center">III. Outline of ore deposits</div>

Two ore zones are known in the district and are called the East ore zone and the West ore zone (Fig. 2). Dimensions of the ore deposits in the West ore zone are generally larger than those of the East ore zone, so, the ore deposits in the former are economically important. The ore deposits in the

Table 2.   Dimension, principal ore minerals, and country rocks of
ore deposits in the Kamaishi mining district.

No. of ore deposit in Fig. 2	Name of ore deposit	Principal ore minerals	Country rocks	Length along strike of ore body (m)	Maximum thickness of ore body (m)	Depth of ore body (m)
1	Aonoki	magnetite	diorite & skarn	50	40	10+
2	Ômine	magnetite	hornfels & skarn	?	?	?
3	Ômine mine	chalcopyrite	hornfels & skarn	60	30	75+
4	Akaiwa	magnetite	granodiorite & skarn	70	30	120+
5	Sahinai	magnetite	diorite, granodiorite, Later porphyrite, & skarn	250	40	250+
6	Aoban	magnetite	diorite, hornfels, & skarn	80	20	50+
7	Motoyama	magnetite	hornfels & skarn	20–40	10	?
8	Tengumori	chalcopyrite	hornfels, marble, & skarn	260	30	70
9	Shinyama	magnetite & chalcopyrite	porphyrite, marble, & skarn	150–300	100	400+
10	Daisen	magnetite	porphyrite, hornfels, marble, & skarn	30	5	25+
11	Nozoki	magnetite	porphyrite, marble, & skarn	120	5	?
12	Maeyama	magnetite	diorite, hornfels, & skarn	50	10	50+
13	Hosogoe	magnetite	hornfels & skarn	100	10	40+
14	Medake	magnetite	diorite & skarn	30	10	?
15	Odake	magnetite	porphyrite, marble, & skarn	10–100	10	?
16	Takamae	magnetite	porphyrite & skarn	70	20	10+
17	Kabayama	magnetite	porphyrite, marble, & skarn	60	20	50+

district are developed near the contact of limestone of Permian age with
intrusive rocks of probable Cretaceous age or slate of Permian age.

The main contact metasomatic ore deposits in the district will be briefly
described below. Dimensions, principal ore minerals, and country rocks of
these ore deposits are shown in Table 2.

Aonoki ore deposit

The Aonoki ore deposit occurs as an irregular lens of magnetite in diorite.
There appears to be no marble in the ore deposit. The diorite is extensively
replaced by skarn minerals. The ore is made up chiefly of magnetite and is
mined by surface and underground methods. In places small amounts of
chalcopyrite and pyrrhotite are observed to have been disseminated in magnet-
ite. Amphibole, axinite, calcite, clinopyroxene, epidote, garnet, quartz, and
tourmaline are the skarn minerals observed in the ore deposit. As described

before several pegmatite dikes cutting diorite, skarn, and ore are found in the ore deposit.

Ômine mine

The Ômine mine is under the direction of the Tôyô Mining Co. Ltd.. In 1956 about 1,100 tons of copper concentrate containing about 8 per cent of copper were produced from this mine. The crude ore contains about 2 per cent of copper.

The ore deposit occurs in biotite hornfels along the contact with the Aonoki quartz diorite. There appears to be no marble in the ore deposit. It is a spindle-shaped mass with the long axis plunging vertical. Skarns are made up chiefly of clinopyroxene, epidote, garnet, quartz with small amounts of amphibole and axinite. Sulphide ore is disseminated in skarns. Under the microscope the ore is seen to be composed of chalcopyrite, cubanite, pyrrhotite with small amounts of magnetite, pentlandite, and sphalerite.

Sahinai and Aoban ore deposits

Next to the Shinyama ore deposit, the Sahinai ore deposit is the largest ore deposit in this district. The iron ore forming the Sahinai ore deposit is mined by surface and underground methods.

The Sahinai and Aoban ore deposits are irregular, lenticular masses of magnetite occurring near the contact of diorite. The ore deposits have a north strike and a steep westerly dip. No marble is observed in these ore deposits. As can be seen from the distribution of skarns (Fig. 2), however, the original rock of skarns forming the ore deposits is thought to have mostly been limestone of the Kasshi formation. The diorite and Ganidake granodiorite adjacent to skarns are extensively skarnized in the Sahinai ore deposit. Clinopyroxene and garnet are common constituents of the ore.

Tengumori ore deposit

The Tengumori ore deposit occurs in marble along the contact with biotite hornfels, and consists of small, irregular lenses of garnet-pyroxene skarn. Small amounts of chalcopyrite and pyrrhotite are disseminated in the skarn. The ore deposit has a northwest strike and a steep or gentle westerly dip.

Shinyama ore deposit

The Shinyama ore deposit is the largest ore deposit in this district, and consists of four ore bodies, namely- the Iron, First Iron-Copper, Second Copper, and Third Copper ore bodies (Fig. 4). The original rocks of skarns in these ore bodies are limestone and porphyrite.

The Iron and First Iron-Copper ore bodies occur as irregular masses in porphyrite. Marble is only observed at one place in the Iron ore body. The crude ore of the Iron ore body contains about 30–35 per cent of iron, and that of the First Iron-Copper ore body also contains about 30–35 per cent of iron with 0.1 per cent of copper.
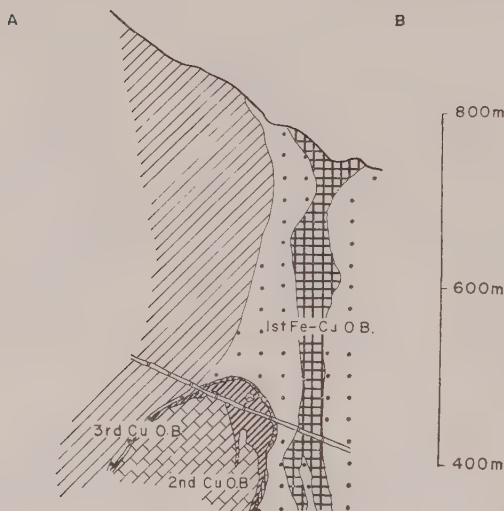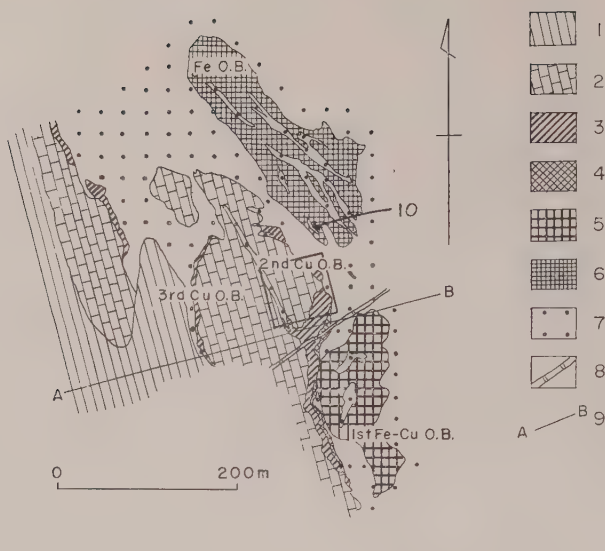
Fig. 4. Geologic map (plan of 450 meters-level and section of S160)
of Shinyama ore deposit.
Key. 1–hornfels, 2–marble, 3–dark green pyroxene skarn partly replaced by
sulphide ore minerals, 4–garnet-pyroxene skarn, 5–skarns partly replaced
by magnetite associated with small amounts of sulphide ore minerals, 6–
skarns partly replaced by magnetite, 7–skarnized porphyrite, 8–lamprophyre,
9–section, 10–cross-cut tunnel S40, 450 meters-level, Iron ore body, □–area
shown in isometric block diagram (Fig. 5).

The Second and Third Copper ore bodies occur as tabular masses near
the boundary between marble and porphyrite. In the places where apophysis
of porphyrite extends into marble, ore and skarn are developed along the
contact (Fig. 5). These two ore bodies are connected with each other in the
upper part of the ore bodies. The crude ore of the ore bodies contains about
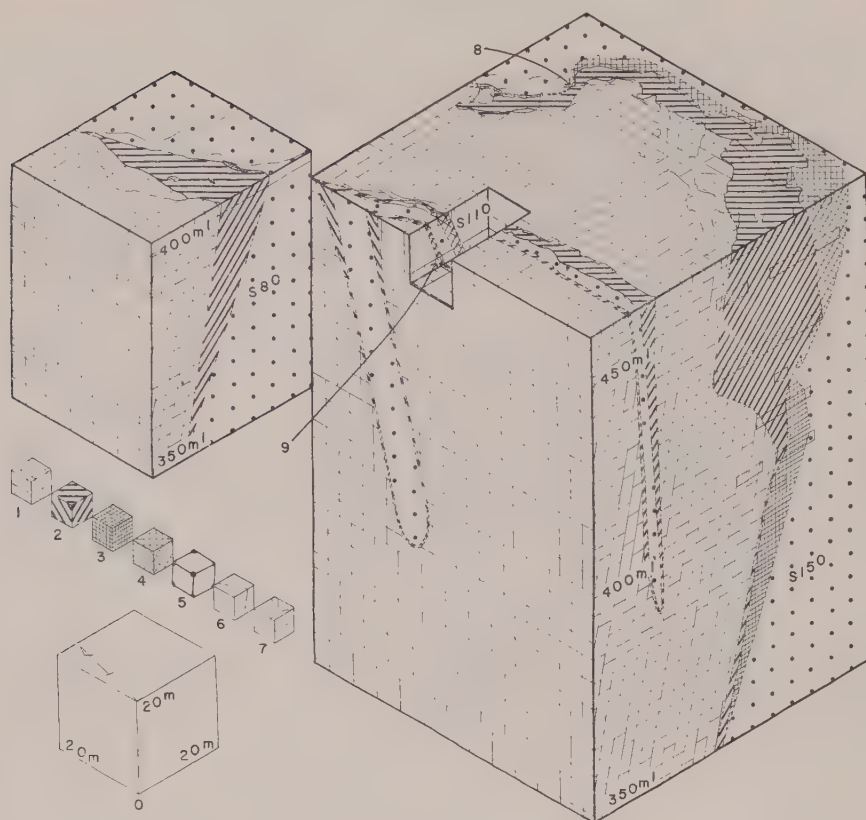
Fig. 5. Isometric block diagram of Second Copper ore body.
Key. 1–marble, 2–dark green pyroxene skarn partly replaced by sulphide ore minerals, 3–dark green pyroxene or garnet-pyroxene skarn partly replaced by magnetite, 4–garnet-pyroxene skarn, 5–skarnized porphyrite, 6–rock boundaries, 7–tunnel, 8–S90, sub-level, 450 meters-level, 9–cross-cut tunnel S110, 450 meters-level.

Table 3. Dimensions and principal ore minerals of ore bodies
in the Shinyama ore deposit.

Name of ore body	Principal ore minerals	Length along strike of ore body (m)	Maximum thickness of ore body (m)	Depth of ore body (m)
Iron	magnetite	300	100	400+
First Copper-Iron	magnetite & chalcopyrite	200	70	400+
Second Copper	chalcopyrite	300	25	100+
Third Copper	chalcopyrite	100	2	100+

1 per cent of copper.

Dimensions and principal ore minerals of the ore bodies in the Shinyama ore deposit are shown in Table 3.

Daisen and Nozoki ore deposits

The Daisen and Nozoki ore deposits are irregular, lenticular masses of magnetite occurring at or near the contact of porphyrite with marble. They have a northwest strike and a steep easterly dip. The porphyrite is extensively replaced by skarn minerals. In places small amounts of arsenopyrite, chalcopyrite, and pyrrhotite are disseminated in magnetite. Amphibole, axinite, calcite, clinopyroxene, epidote, garnet, quartz, and tourmaline are the skarn minerals observed in the ore deposits.

IV. Contact-reaction-metasomatic phenomena

In order to study contact-reaction-metasomatic phenomena during the formation of skarns and metasomatic phenomena during the formation of paigeite rock and ores in the district, the writer selected the Shinyama ore deposit, because it is a representative and well exploited one among the many ore deposits of the district. In this chapter the description of skarns and surrounding rocks found in the ore deposit will be given in the order from porphyrite to marble, then, the genetical consideration of them will be discussed. The typical modes of occurrence of these rocks will be shown in Figs. 6 and 7, and Plate V, Figs. 1 and 2, and the chemical composition of them will be given in Tables 4, 6, and 8.

1. Skarns and surrounding rocks

Sericitized porphyrite

Sericitized porphyrite is a gray colored rock with phenocrysts of idiomorphic plagioclase and amphibole set in a fine-grained groundmass. Under the microscope plagioclase of both phenocrysts and the groundmass is seen to have mostly been altered to sericite. Porphyrites found in the Shinyama ore deposit are, more or less, altered. These are sericitized porphyrite and biotite-rich altered porphyrite which will be described in the next section. Sericitized porphyrite occurring at the sub-level S90 on the 450 meters-level in the Second Copper ore body will be described below.

As shown in Fig. 6, this rock forms island-like masses within biotite-rich altered porphyrite at this locality.

Phenocrysts of the rock are plagioclase and amphibole, and reach 2 millimeters in length. The groundmass is composed of fine-grained plagioclase, amphibole, and a small amount of quartz. As stated before plagioclase of both phenocrysts and the groundmass is seen to have mostly been altered to sericite. The writer was not able to determine the composition of plagioclase because of its alteration. The pleochroic scheme of amphibole of both phenocrysts and the groundmass is: X= pale yellow, Y= greenish yellow, Z= green. Its refractive index is $\gamma=1.690$. Its optical character is negative and the 2V is large. Several small grains of magnetite are observed in amphibole.
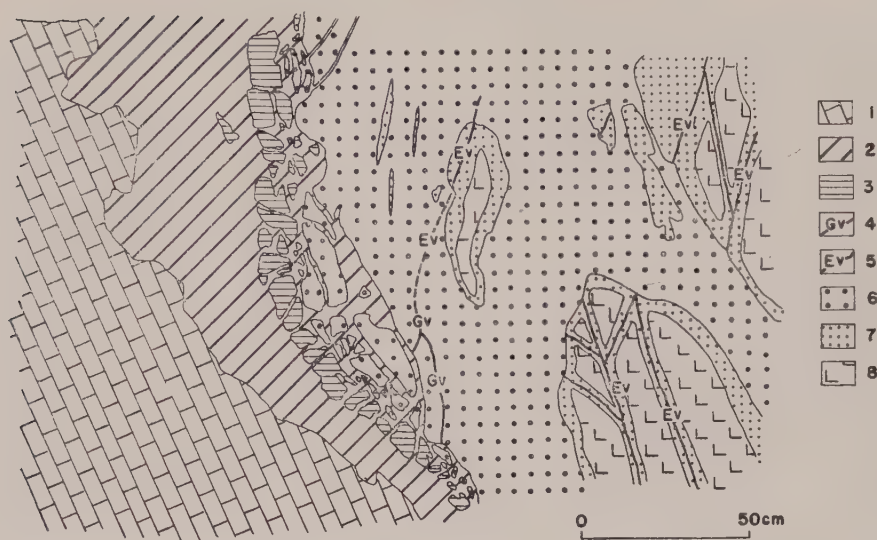
Fig. 6. Sketch showing the mode of occurrence of skarns.
Key. 1–marble, 2–dark green pyroxene skarn, 3–garnet-pyroxene skarn, 4–garnet vein, 5–epidote vein, 6–epidote skarn, 7–biotite-rich altered porphyrite, 8–sericitized porphyrite. Loc. S90, sub-level, 450 meters-level, Second Copper ore body, Shinyama ore deposit.

As accessory minerals, apatite and sphene are present.

Biotite-rich altered porphyrite

Biotite-rich altered porphyrite is dark brown in color, and occurs widely in the Shinyama ore deposit. The rock is developed as island-like masses in partly epidotized porphyrite or in epidote-amphibole skarn, or is developed as a zone between sericitized porphyrite and epidote-amphibole skarn. The description of the rock found at the sub-level S90 on the 450 meters-level in the Second Copper ore body will be given below.

As shown in Fig. 6 the rock occurs between sericitized porphyrite and epidote-amphibole skarn at this locality. The zone of this rock ranges from a few centimeters to a few decimeters in width.

The porphyritic texture of the rock is not evident with the unaided eye, but, under the microscope, the texture is seen to be well preserved. Phenocrysts consist of plagioclase reaching 2 millimeters in length, and the groundmass consists mainly of fine-grained plagioclase, biotite, amphibole, and a small amount of quartz. Plagioclase of both phenocrysts and the groundmass is seen to have mostly been replaced by sericite and epidote. The composition of plagioclase could not be determined because of its alteration. The refractive indices of epidote are $\alpha=1.730$, $\gamma=1.769$. According to TRÖGER'S (1956) diagram of epidote, these optical properties correspond to about 30 mol. per cent of the $HCa_2Fe_3Si_3O_{13}$ molecule. In the following description the chemical composition of other epidotes will be inferred in the same manner. Biotite forms small flakes. The pleochroic scheme of biotite is: X= pale

Table 4. Chemical composition of skarns and surrounding rocks.

	1		2		3		4		5	
	Wt. %	Mol. r.	Wt. %	Mol. r.	Wt. %	Mol. r.	Wt. %	Mol. r.	Wt. %	Mol. r.
SiO_2	48.15	0.8017	37.27	0.6206	38.28	0.6374	45.17	0.7521	0.17	0.0028
Al_2O_3	19.89	0.1951	19.43	0.1906	9.54	0.0936	0.32	0.0031	0.11	0.0011
TiO_2	0.40	0.0050	0.31	0.0039	0.33	0.0041	0.05	0.0006	0.01	0.0001
Fe_2O_3	2.07	0.0130	12.13	0.0760	12.58	0.0788	2.05	0.0128	0.00	0.0000
FeO	10.03	0.1396	2.66	0.0370	2.85	0.0397	19.85	0.2367	0.32	0.0045
MnO	0.32	0.0045	0.24	0.0034	0.74	0.0104	1.22	0.0172	0.01	0.0001
MgO	3.92	0.0972	0.66	0.0164	1.51	0.0375	3.88	0.0962	0.26	0.0065
CaO	6.69	0.1193	23.46	0.4183	32.07	0.5719	24.19	0.4314	55.22	0.9846
Na_2O	2.18	0.0352	0.14	0.0023	0.19	0.0031	0.30	0.0048	0.15	0.0024
K_2O	3.35	0.0356	0.02	0.0002	0.11	0.0012	0.08	0.0009	0.09	0.0010
H_2O+	2.04	0.1132	1.55	0.0860	0.02	0.0011	0.02	0.0011	0.00	0.0000
H_2O-	0.17	0.0094	0.00	0.0000	0.00	0.0000	0.08	0.0044	0.00	0.0000
P_2O_5	0.52	0.0037	0.06	0.0004	0.25	0.0018	0.06	0.0004	0.02	0.0001
CO_2	0.35	0.0080	2.20	0.0500	1.64	0.0373	2.99	0.0680	43.54	0.9896
	100.08		100.13		100.11		100.26		99.90	
Specific gravity	2.9		3.3		3.5		3.4		2.7	

1 Biotite-rich altered porphyrite. Loc. S90, sub-level, 450 meters-level, Second Copper ore body, Shinyama ore deposit.
2 Epidote-amphibole skarn. Loc. Ditto.
3 Garnet-pyroxene skarn. Loc. Ditto.
4 Dark green pyroxene skarn. Loc. Ditto.
5 Marble. Loc. Ditto.

(Anal. H. Haramura)

yellow, Y & Z= reddish brown. Its refractive index is $\beta=1.652$. Amphibole shows distinct pleochroism: X= pale yellow, Y= greenish yellow, Z= light green, with a refractive index of $\gamma=1.698$. Its optical character is negative and the 2V is large. Several small grains of magnetite are observed within amphibole and biotite.

The boundary between sericitized porphyrite and biotite-rich altered porphyrite is sharp.

Partly epidotized porphyrite

Partly epidotized porphyrite is a gray colored rock with phenocrysts of idiomorphic plagioclase set in a fine-grained groundmass. Under the microscope plagioclase of both phenocrysts and the groundmass is seen to have been partly replaced by epidote and sericite. In the vicinity of the contact between endo- and exo-skarns, partly epidotized porphyrite is not developed, whereas, a few meters away from the contact toward porphyrite, the rock is developed between biotite-rich altered porphyrite and epidote-amphibole skarn. The rock occurring at the cross-cut tunnel N120 on the 400 meters-level in the Iron ore body will be described below.

At this locality the zone of this rock ranges from a few centimeters to a few decimeters in width. Phenocrysts consist of plagioclase reaching 2 millimeters in length, and the groundmass consists chiefly of fine-grained plagioclase, amphibole, and small amounts of microcline and quartz.

The boundary of biotite-rich altered porphyrite to partly epidotized porphyrite is sharp.

Epidote-amphibole skarn

Epidote-amphibole skarn is grassy green in color and made up mainly of epidote and amphibole. This skarn is the most widely developed one among the endo-skarns found in the Shinyama ore deposit. The skarn is found between epidote-pyroxene skarn and biotite-rich altered porphyrite or partly epidotized porphyrite. The description of this rock occurring at the sub-level S90 on the 450 meters-level in the Second Copper ore body will be given below.

The skarn occurs between biotite-rich altered porphyrite and epidote-pyroxene skarn at this locality. In Fig. 6 epidote-amphibole and epidote-pyroxene skarns are not separated and are lumped under the name of epidote skarn because of the difficulty of setting up a distinction between these skarns in the field. The epidote-amphibole skarn zone ranges from a few centimeters to about 1 meter in width, whereas, the epidote-pyroxene skarn zone is only

Table 5. Chemical composition of epidote from epidote-amphibole skarn.
Loc. S90, sub-level, 450 meters-level, Second Copper ore body.

	Wt. %	Mol. ratio	Atomic ratios on the anhydrous basis of O=12.5		
SiO_2	36.59	0.6092	Si	2.938	2.938
Al_2O_3	22.09	0.2167	Ti	0.016	
TiO_2	0.27	0.0034	Al	2.090	
Fe_2O_3	14.30	0.0896	Fe^{+3}	0.864	2.966
FeO	0.92	0.0128	Mn	0.012	
MnO	0.18	0.0025	Fe^{+2}	0.062	
MgO	0.16	0.0040	Mg	0.019	
CaO	23.54	0.4198	Ca	2.024	2.024
Na_2O	0.13	0.0021	Na	0.020	
K_2O	0.00	0.0000	K	0.000	
H_2O+	2.09	0.1160	H	1.119	
H_2O-	0.17	0.0094	P	0.013	
P_2O_5	0.20	0.0014			
	100.64				
α	1.738		Al : Fe^{+3}=0.71 : 0.29		
β	1.751				
γ	1.775				
2V	71°(−)				

(Anal. H. HARAMURA)

a few centimeters in width along garnet veins.

Epidote-amphibole skarn is granoblastic in texture. Grains of epidote may go up to about 1 millimeter, while, those of amphibole to about 0.5 millimeter. Refractive indices of epidote in the skarn developed near biotite-rich altered porphyrite are $\alpha=1.734$, $\gamma=1.774$, and those of epidote in the skarn developed near epidote-pyroxene skarn are $\alpha=1.739$, $\gamma=1.774$. Epidote occurring in the central part of this zone was separated and analyzed. The chemical composition of the mineral is given in Table 5 together with its optical properties. The result revealed that the epidote has the composition, $(Ca_2Fe_3(OH)Si_3O_{12})_{29}(Ca_2Al_3(OH)Si_3O_{12})_{71}$. As can be seen from these data, variation in the chemical composition of epidote in this zone is small. Amphibole is present at the boundary of epidote grains. The pleochroic scheme of amphibole is: X= yellow, Y= greenish yellow, Z= green, with a refractive index of $\gamma=1.682$. Its optical character is negative and the 2V is large. As accessory minerals, apatite and sphene are observed. Extremely small amounts of magnetite and ilmenite occur in amphibole. These two minerals may have been relict minerals. Small amounts of calcite, quartz, and chalcopyrite of probable hysterogenic origin are found in druses.

The boundary between biotite-rich altered porphyrite and epidote-amphibole skarn is sharp. The boundary between partly epidotized porphyrite and epidote-amphibole skarn is also sharp.

Epidote-pyroxene skarn

Epidote-pyroxene skarn is grassy green in color and consists mostly of epidote and clinopyroxene. In the preceding section, incidental mention has already been made of one of the occurrences of the skarn. In the places where porphyrite dike intrudes limestone, and both of them are replaced by skarns, the epidote-pyroxene skarn zone is wider here than the areas where large amounts of porphyrite and marble are found. The skarn occurring at the cross-cut tunnel S110 on the 450 meters-level in the Second Copper ore body will be described below.

From the mode of occurrence of skarns, it is evident that porphyrite dike intrudes limestone, and both of them are subsequently replaced by skarns at this locality. As shown in Fig. 7 indicating the left half of zoned skarns, epidote-pyroxene skarn is found as kidneys within pale green pyroxene skarn. Kidneys of the skarn range from a few centimeters to about 2 meters in diameter.

Epidote-pyroxene skarn is granoblastic in texture, and consists chiefly of epidote and clinopyroxene reaching 1 millimeter in length. Optical properties of epidote in the skarn developed near pale green pyroxene skarn are: $\alpha=1.736$, $\gamma=1.773$, corresponding to about 35 mol. per cent of the $HCa_2Fe_3Si_3O_{13}$ molecule. Optical properties of the coexisting clinopyroxene are: $\alpha=1.689$, $\gamma=1.723$, $(+)2V=57°$. According to Hess' (1949) diagrams of clinopyroxene, these optical properties correspond to 35–45 atomic per cent of $Fe^{+2}/Fe^{+2}+Mg$. In the following description the chemical composition of other clinopyroxenes
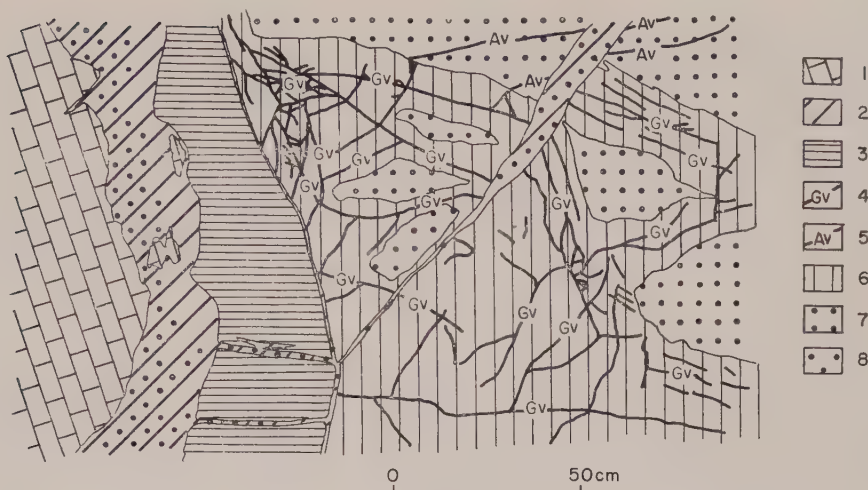
Fig. 7.   Sketch showing the mode of occurrence of skarns.
Key. 1–marble, 2–dark green pyroxene skarn, 3–garnet-pyroxene skarn,
4–garnet vein, 5–axinite vein, 6–pale green pyroxene skarn, 7–epidote-
pyroxene skarn, 8–dark green pyroxene skarn partly replaced by sulphide
ore minerals. Loc. Cross-cut tunnel S110, 450 meters-level, Second Copper
ore body, Shinyama ore deposit.

Table 6.   Chemical composition of skarns.

	1		2		3		4	
	Wt. %	Mol. r.	Wt. %	Mol. r.	Wt. %	Mol. r.	Wt. %	Mol. r.
SiO_2	42. 30	0. 7043	47. 36	0. 7886	39. 62	0. 6597	44. 35	0. 7384
Al_2O_3	12. 73	0. 1249	0. 20	0. 0020	7. 53	0. 0739	0. 05	0. 0005
TiO_2	0. 55	0. 0069	0. 62	0. 0078	0. 09	0. 0011	0. 02	0. 0003
Fe_2O_3	8. 52	0. 0534	4. 23	0. 0265	13. 80	0. 0864	3. 08	0. 0193
FeO	5. 98	0. 0832	14. 18	0. 1974	3. 63	0. 0505	18. 65	0..2596
MnO	0. 46	0. 0065	0. 68	0. 0096	0. 67	0. 0095	0. 96	0. 0135
MgO	4. 01	0. 0995	5. 93	0. 1471	0. 92	0. 0228	4. 17	0. 1034
CaO	22. 36	0. 3987	22. 65	0. 4039	30. 87	0. 5505	22. 23	0. 3964
Na_2O	1. 70	0. 0274	1. 70	0. 0274	0. 78	0. 0126	1. 02	0. 0165
K_2O	0. 36	0. 0038	0. 34	0. 0036	0. 22	0. 0023	0. 22	0. 0023
H_2O+	0. 58	0. 0322	0. 44	0. 0244	0. 00	0. 0000	0. 05	0. 0028
H_2O-	0. 00	0. 0000	0. 00	0. 0000	0. 00	0. 0000	0. 00	0. 0000
P_2O_5	0. 26	0. 0018	0. 28	0. 0020	0. 02	0. 0001	0. 05	0. 0004
CO_2	0. 75	0. 0171	1. 98	0. 0450	2. 43	0. 0552	5. 75	0. 1307
	100. 56		100. 59		100. 58		100. 60	
Specific gravity	3. 3		3. 3		3. 5		3. 3	

1   Epidote-pyroxene skarn. Loc. Cross-cut tunnel S110, 450 meters-level, Second
    Copper ore body, Shinyama ore deposit.
2   Pale green pyroxene skarn. Loc. Ditto.
3   Garnet-pyroxene skarn. Loc. Ditto.
4   Dark green pyroxene skarn. Loc. Ditto.
                              (Anal. H. HARAMURA)

will be inferred in the same manner.

As accessory minerals, apatite and sphene are present. Small amounts of calcite and quartz are found in this skarn developed near epidote veins. These two minerals may have been hysterogenic ones.

In the places where large amounts of porphyrite and marble are found, the boundary between epidote-amphibole skarn and epidote-pyroxene skarn is sharp. No coexistent grains of amphibole and clinopyroxene are observed at this boundary, these two minerals are always separated by grains of epidote.

Pale green pyroxene skarn

This skarn is pale green in color and is made up mainly of clinopyroxene. It is only found in the places where porphyrite dike intrudes limestone, and both of them are replaced by skarns. The description of this rock developed at the cross-cut tunnel S110 on the 450 meters-level in the Second Copper ore body will be given below.

As shown in Fig. 7 the skarn occurs between epidote-pyroxene skarn and garnet veins. The skarn zone ranges from a few centimeters to about a few decimeters in width.

Pale green pyroxene skarn is granoblastic in texture, and consists of clinopyroxene reaching 1 millimeter in length. Optical properties of clino-pyroxene in the skarn found near epidote-pyroxene skarn are: $\alpha=1.684$, $\gamma=1.717$, $(+)2V=57°$, corresponding to about 25–35 atomic per cent of $Fe^{+2}/Fe^{+2}+Mg$, while those in the skarn found near garnet veins are: $\alpha=1.704$, $\gamma=1.732$, $(+)2V=59°$, corresponding to about 58 atomic per cent of $Fe^{+2}/Fe^{+2}+Mg$. As accessory minerals, apatite and sphene are present. Small amounts of calcite and quartz are found in the skarn developed near garnet veins. An extremely small amount of amphibole is observed along cleavages of clino-pyroxene. These three minerals may have been hysterogenic ones.

The boundary between epidote-pyroxene skarn and pale green pyroxene skarn is sharp.

Garnet-pyroxene skarn

Garnet-pyroxene skarn is mainly found as exo-skarn, and rarely as endo-skarn. The exo-skarn will be described in this section.

In the places where large amounts of marble and porphyrite are develop-ed, the skarn is frequently found as island-like masses in dark green pyroxene skarn. The mode of occurrence of the skarn occurring at the sub-level S90 on the 450 meters-level in the Second Copper ore body is shown in Fig. 6. At this locality the zone of the skarn is about 10 centimeters in width.

The skarn is granoblastic in texture, and consists of isotropic garnet and clinopyroxene. These minerals measure 0.5–1 millimeter in diameter. Optical properties of clinopyroxene in the skarn are: $\alpha=1.672$, $\gamma=1.704$, $(+)2V=57°$, corresponding to 7–14 atomic per cent of $Fe^{+2}/Fe^{+2}+Mg$. The lattice para-meter of the coexisting garnet is: $a_0=11.95Å$, corresponding to about 40 mol. per cent of the andradite molecule. From the chemical composition of garnets

Table 7-1. Chemical composition of garnet from axinite-calcite-epidote-garnet-quartz vein in epidote-pyroxene skarn. Loc. Cross-cut tunnel S100, 400 meters-level, Second Copper ore body.

	Wt. %	Mol. ratio	Atomic ratios on the basis of O=12		
SiO_2	35. 13	0. 5849	Si	2. 880	2. 880
Al_2O_3	8. 50	0. 0834	Ti		
TiO_2	tr.		Al	0. 821	2. 085
Fe_2O_3	20. 49	0. 1283	Fe^{+3}	1. 264	
FeO	0. 87	0. 0121	Fe^{+2}	0. 060	
MnO	0. 66	0. 0093	Mn	0. 046	3. 084
MgO	tr.		Mg		
CaO	33. 91	0. 6047	Ca	2. 978	
Na_2O	0. 34	0. 0055	Na	0. 054	
K_2O	0. 04	0. 0004	K	0. 004	
H_2O+	0. 23	0. 0128			
H_2O-	0. 26	0. 0144	$Fe^{+2} : Mn : Ca = 0. 02 : 0. 01 : 0. 97$		
P_2O_5	tr.		$Al : Fe^{+3} = 0. 39 : 0. 61$		
	100. 43				
			And	61	
a_0(Å)	11. 96		Gr	36	
			Alm	2	
			Sp	1	

(Anal. H. HARAMURA)

Table 7-2. Chemical composition of garnet from garnet skarn partly replaced by magnetite. Loc. Cross-cut tunnel N140, 400 meters-level, Iron ore body.

	Wt. %	Mol. ratio	Atomic ratios on the basis of O=12		
SiO_2	36. 19	0. 6026	Si	2. 892	2. 892
Al_2O_3	14. 08	0. 1381	Ti	0. 003	
TiO_2	0. 05	0. 0006	Al	1. 326	2. 028
Fe_2O_3	11. 67	0. 0731	Fe^{+3}	0. 702	
FeO	1. 41	0. 0196	Fe^{+2}	0. 094	
MnO	0. 56	0. 0079	Mn	0. 038	3. 153
MgO	0. 28	0. 0069	Mg	0. 033	
CaO	34. 91	0. 6225	Ca	2. 988	
Na_2O	0. 19	0. 0031	Na	0. 030	
K_2O	tr.				
H_2O+	0. 46	0. 0255			
H_2O-	0. 13	0. 0072	$Fe^{+2} : Mn : Mg : Ca = 0. 03 : 0. 01 : 0. 01 : 0. 95$		
P_2O_5	tr.		$Al : Fe^{+3} = 0. 65 : 0. 35$		
	99. 93				
			And	35	
a_0(Å)	11. 91		Gr	60	
			Alm	3	
			Sp	1	
			Py	1	

(Anal. H. HARAMURA)

Table 7-3. Chemical composition of garnet from calcite-epidote-garnet-
quartz vein. Loc. Cross-cut tunnel N140, 400
meters-level, Iron ore body.

	Wt. %	Mol. ratio	Atomic ratios on the basis of O=12		
SiO_2	36. 06	0. 6004	Si	2. 918	2. 918
Al_2O_3	9. 55	0. 0937	Ti	0. 005	
TiO_2	0. 08	0. 0010	Al	0. 911	2. 055
Fe_2O_3	18. 80	0. 1177	Fe^{+3}	1. 144	
FeO	1. 23	0. 0171	Fe^{+2}	0. 083	
MnO	0. 76	0. 0107	Mn	0. 052	3. 061
MgO	tr.		Mg		
CaO	33. 76	0. 6020	Ca	2. 926	
Na_2O	0. 14	0. 0023	Na	0. 022	
K_2O	tr.				
H_2O+	0. 23	0. 0128			
H_2O-	0. 05	0. 0028	Fe^{+2} : Mn : Ca=0. 03 : 0. 02 : 0. 95		
P_2O_5	tr.		Al : Fe^{+3}=0. 44 : 0. 56		
	100. 66				
a_0(Å)	11. 95		And	56	
			Gr	39	
			Alm	3	
			Sp	2	

(Anal. H. HARAMURA)

found in the Shinyama ore deposit (Table 7-1, 2, 3), it can be supposed that
garnets found in the ore deposit may be composed of 3-5 mol. per cent of
the pyralspite molecule and 95-97 mol. per cent of the grandite molecule.
Assuming, then, the preservation of the ratio of the pyralspite molecule to
the grandite molecule in garnet found in the ore deposit, the approximate
chemical composition of garnet can be determined by the measurement of
the lattice parameter of garnet, using SRIRAMADAS' (1957) diagrams of garnet.
In the following description the chemical composition of other garnets will
be inferred in the same manner.

No sphene is observed in the skarn. Small amounts of calcite and quartz
are found in the skarn developed near dark green pyroxene skarn partly
replaced by amphibole, calcite, and quartz. The clinopyroxene found along
such dark green pyroxene skarn is partly replaced by amphibole. These
three minerals may have been hysterogenic ones.

In the places where porphyrite dike intrudes limestone, and both of
them are replaced by skarns, the garnet-pyroxene skarn zone is found
between dark green pyroxene skarn and dark green pyroxene vein. The
mode of occurrence of the skarn occurring at the cross-cut tunnel S110
on the 450 meters-level in the Second Copper ore body is shown in Fig. 7.
At this locality the skarn zone is 20-40 centimeters in width. The skarn is
granoblastic in texture, and consists of clinopyroxene and anomalous garnet.

These minerals measure 0.5–1 millimeter in diameter. Optical properties of clinopyroxene in the central part of the skarn zone are: $\alpha=1.700$, $\gamma=1.736$, $(+)2V=59°$, corresponding to about 50–65 per cent of $Fe^{+2}/Fe^{+2}+Mg$. The lattice parameter of the coexisting garnet is $a_0 \doteqdot 11.94 Å$, corresponding to about 40 mol. per cent of the andradite molecule.

Garnet-pyroxene skarn is also found along garnet veins in pale green pyroxene skarn or epidote-pyroxene skarn. But, such garnet-pyroxene skarn is only a few millimeters in width.

Garnet skarn

Garnet skarn is pale brown in color and is made up mainly of isotropic or slightly anomalous garnet. This skarn is found as exo-skarn and also endo-skarn. The skarn occurs as a zone between epidote-pyroxene skarn and marble. In the limestone-side of the zone, garnet skarn is frequently replaced by magnetite and paigeite which will be described later. The description of garnet skarn occurring at the cross-cut tunnel S40 on the 450 meters-level in the Iron ore body will be given below.

The skarn occurs between epidote-pyroxene skarn and marble at this locality. The garnet zone is about 20 meters in width. Garnet skarn developed near epidote-pyroxene skarn is granoblastic in texture. Grains of

Table 8. Chemical composition of skarns.

	1		2		3	
	Wt. %	Mol. r.	Wt. %	Mol. r.	Wt. %	Mol. r.
SiO_2	40. 97	0. 6822	33. 76	0. 5621	33. 72	0. 5614
Al_2O_3	14. 88	0. 1460	9. 56	0. 0938	4. 31	0. 0423
TiO_2	0. 31	0. 0039	0. 37	0. 0046	0. 19	0. 0024
Fe_2O_3	12. 44	0. 0779	12. 14	0. 0760	20. 49	0. 1283
FeO	1. 34	0. 0187	0. 75	0. 0104	0. 64	0. 0089
MnO	0. 32	0. 0045	0. 52	0. 0073	0. 49	0. 0069
MgO	2. 78	0. 0690	0. 43	0. 0107	0. 27	0. 0067
CaO	25. 69	0. 4581	35. 60	0. 6348	36. 07	0. 6432
Na_2O	0. 28	0. 0045	0. 04	0. 0007	0. 04	0. 0007
K_2O	0. 19	0. 0020	0. 13	0. 0014	0. 03	0. 0003
H_2O+	0. 41	0. 0228	0. 38	0. 0211	0. 72	0. 0400
H_2O-	0. 07	0. 0039	0. 06	0. 0033	0. 05	0. 0028
P_2O_5	0. 14	0. 0010	0. 83	0. 0058	0. 11	0. 0008
CO_2	0. 00	0. 0000	5. 40	0. 1227	1. 36	0. 0309
	99. 82		99. 97		98. 49	
Specific gravity	3. 3		3. 3		3. 6	

1 Epidote-pyroxene skarn. Loc. Cross-cut tunnel S40, 450 meters-level, Iron ore body, Shinyama ore deposit.
2 Garnet skarn. Loc. Ditto.
3 Garnet skarn. Loc. Ditto.

(Anal. M. IKAWA)

garnet may go up to about 1 millimeter. Garnet skarn near marble consists chiefly of garnet and calcite. The skarn is poikiloblastic in texture, namely-fine-grained and globular crystals of garnet are embedded in calcite. From the garnet skarn developed near epidote-pyroxene skarn to that developed near marble, the lattice parameter of garnet varies as follows: 11.93Å, corresponding to 47 mol. per cent of the andradite molecule; 11.94Å, corresponding to 50 mol. per cent of the andradite molecule; 11.95Å, corresponding to 57 mol. per cent of the andradite molecule; 11.97Å, corresponding to 67 mol. per cent of the andradite molecule. In the garnet skarn found near paigeite rock, small amounts of apatite, tourmaline, chalcopyrite, and sphalerite are developed.

The boundary between garnet skarn and epidote-pyroxene skarn, and that between garnet skarn and paigeite rock are sharp.

Dark green pyroxene skarn

The skarn is dark green in color and consists chiefly of clinopyroxene. This skarn is the most widely developed one among the many exo-skarns in the Second and Third Copper ore bedies. The skarn is always found between garnet-pyroxene skarn and marble, and ranges from a few centimeters to about 20 meters in width. However, dark green pyroxene skarn proper is rarely observed in the ore bodies because of the selective replacement by magnetite and sulphide minerals which will be described later. The description of the skarn occurring at the cross-cut tunnel S110 on the 450 meters-level in the Second Copper ore body will be given below.

At this locality this skarn zone is a few centimeters in width. The skarn is granoblastic in texture and consists mainly of clinopyroxene reaching 1 millimeter in length. Optical properties of clinopyroxene in the skarn developed near garnet-pyroxene skarn are: $\alpha=1.716$, $\gamma=1.745$, $(+)2V=61°$, corresponding to about 80 atomic per cent of $Fe^{+2}/Fe^{+2}+Mg$, while those in the skarn developed near marble are: $\alpha=1.715$, $\gamma=1.749$, $(+)2V=59°$, corresponding to about 77–88 atomic per cent of $Fe^{+2}/Fe^{+2}+Mg$. No apatite and sphene are observed in the skarn.

The boundary between garnet-pyroxene skarn and dark green pyroxene skarn is sharp.

Marble

Marble is widely found in the Second Copper and Third Copper ore bodies, whereas, the rock is only found at the cross-cut tunnel S40 on the 450 meters-level in the Iron ore body. The rock is saccharoidal and white. Under the microscope the rock is seen to be composed almost exclusively of intricately twinned calcite grains averaging 1 millimeter in size. The boundary between dark green pyroxene skarn and marble, and that between granet skarn and marble are sharp.

Impure layers are frequently observed in marble developed near exo-skarns. The impure layers consist of amphibole, apatite, calcite, magnetite, paigeite, phlogopite, and sphalerite.

Skarn veins

Skarn veins are often found in endo-skarns, whereas, these veins are rarely observed in exo-skarns. Endo-skarns are zonally developed along skarn veins. Skarn veins occurring at the cross-cut tunnel S110 on the 450 meters-level in the Second Copper ore body will be described below.

The mode of occurrence of skarn veins at this locality is shown in Fig. 7. From the marble-side to the porphyrite-side, the mineral constituting skarn veins varies as follows: 1) clinopyroxene; 2) garnet; 3) epidote or axinite. In these skarn veins, moderate amounts of calcite and quartz are always observed, however, calcite and quartz pseudomorphs after clinopyroxene, garnet, epidote, and axinite are frequently observed. Therefore, calcite and quartz may have been hysterogenic minerals.

Dark green pyroxene veins are observed in garnet-pyroxene skarn and pale green pyroxene skarn. The skarn veins range from a few millimeters to a few centimeters in width. Crystals of clinopyroxene are prismatic and reach a few millimeters in length. Optical properties of clinopyroxene in these veins are: $\alpha=1.700$, $\gamma=1.740$, $(+)2V=59°$, corresponding to 52–72 atomic per cent of $Fe^{+2}/Fe^{+2}+Mg$. Clinopyroxene is partly replaced by amphibole, calcite, quartz, and magnetite.

Dark green pyroxene veins change into garnet veins. Garnet veins are found in pale green pyroxene skarn and garnet-pyroxene skarn, and are a few millimeters in width. Crystals of garnet are idiomorphic and anomalous, and reach 4 millimeters in diameter. The lattice parameter of garnet is: $a_0=12.05\text{Å}$, corresponding to almost pure andradite. Garnet is partly replaced by calcite and quartz.

Garnet veins change into epidote or axinite veins. Epidote and axinite veins are found in epidote-pyroxene skarn and epidote-amphibole skarn, and a few millimeters in width. Crystals of epidote and axinite are idiomorphic, and reach 2 millimeters in length. Refractive indices of epidote in this vein are: $\alpha=1.730$, $\gamma=1.770$, corresponding to about 30 mol. per cent of the HCa_2-$Fe_3Si_3O_{13}$ molecule.

2. Genetical consideration

Since the eminent work contributed by LINDGREN (1905) and GOLDSCHMIDT (1911), large amounts of data concerned in the formation of contact metasomatic ore deposits had been accumulated up to 1940. However, it does not appear that much progress has been made in the theory of the formation of these ore deposits during this period. In recent years a considerable amount of progress has been made in understanding the formation of contact metasomatic ore deposits. The work of KORZHINSKY (1940, 1945, 1948, 1950a, 1950b, 1954, 1955, 1957) has been pre-eminent in the theory of formation of skarns. Unfortunately much of KORZHINSKY's work has appeared neither in English nor in English translation, and its full significance has not been widely appreciated.

In the following discussion on the formation of skarns, paigeite rock, and ores, it is assumed that 1) masses of components composing pore fluid were small as compared with those of the enclosing rock at any given moment; 2) the departure from equilibrium relation was insignificant at any point of the rock, that is, the change in the composition of pore fluid was accompanied by an immediate corresponding change in the composition of the enclosing rock; 3) the fluid, which was probably of postmagmatic origin, flowed in fissures during the formation of ore deposits; 4) the surface energy of pore fluid and that of grain of minerals were negligible.

Original rocks of skarns

Original rocks of skarns found in the Shinyama ore deposit are porphyrite and limestone. Endo- and exo-skarns can be distinguished by the presence and absence of sphene in these skarns. Generally speaking, apatite is found in endo-skarns, however, the mineral is also found in exo-skarns as impure layers. From this criterion it may be concluded that skarns occurring in the Shinyama ore deposit were characteristically formed near the boundary between porphyrite and limestone, and that both of them were replaced by skarns.

Mechanism of metasomatic transfer of materials

The interaction between ascending fluid and original rocks of skarns may have been effected in various ways. Two extreme possibilities have been distinguished by KORZHINSKY (1950b, 1954) and others: 1) The fluid ascends an open fissure and permeates the pore of wall-rocks. The interaction between the flowing fluid in the fissure and the wall-rocks is implemented by diffusion through more or less stagnant pore-fluid of walls of the fissure. This process has generally been called the diffusion process. 2) The fluid percolates uniformly through wall-rocks so that each grain of the wall-rocks directly interacts with the fluid, without any essential participation of the diffusion process. This process has been called the infiltration process by KORZHINSKY to distinguish it from the diffusion process.

As shown in Fig. 7, small kidneys of zoned skarns are frequently observed within the network of skarn veins. Judging from this mode of occurrence of skarn veins, the location occupied by skarn veins is thought to have been fissures in original rocks of skarns during the formation of skarns. If these zoned skarns were formed by the infiltration process, there would have been no means of disposal of the spent products of the interaction between each grain of wall-rocks and the fluid. Therefore, the interaction between the wall-rocks and the flowing fluid in fissures is considered to have mainly been implemented by the diffusion process.

The difference between the diffusion and infiltration types of metasomatic zoning will be also reflected in the variability of the composition of metasomatic minerals. This problem was theoretically studied by KORZHINSKY (1952). In infiltration metasomatism, the metasomatic minerals usually behave within each metasomatic zone as minerals of constant composition, whereas, in diffusion metasomatism, compositions of the metasomatic minerals within

each metasomatic zone are moderately variable. Therefore, the fact that the chemical composition of minerals constituting zoned skarns changes continuously, also supports the conclusion.

Paragenesis of minerals in zoned skarns

As can be seen from the description of skarns and surrounding rocks, if the accessory apatite and sphene are neglected, the number of minerals in each zoned skarn is one or two, whereas, that of sericitized porphyrite, biotite-rich altered porphyrite, and partly epidotized porphyrite is greater than two. This fact may be interpreted in two ways. 1) Being apart from fissures in which the fluid participating in the formation of skarn flowed, minerals constituting porphyrite may not have been in equilibrium with the pore fluid because of a decrease in quantity of pore fluid. 2) Being apart from fissures, the number of minerals being in equilibrium with pore fluid may have increased because of the fall of temperature.

As shown in Fig. 6, the total width of zoned skarns and surrounding rocks is only 1 meter at the sub-level S90 on the 450 meters-level in the Second Copper ore body. Therefore, it is difficult to consider that there was a temperature gradient in the wall-rocks during the formation of the zoned skarns and altered porphyrite. So, it may be more reasonable to adopt the former alternative. Then, sericitized porphyrite, biotite-rich altered porphyrite, and partly epidotized porphyrite will be omitted from the following discussion.

A similarity of temperature and pressure during the formation of zoned skarns will be assumed in the following discussion. Components constituting
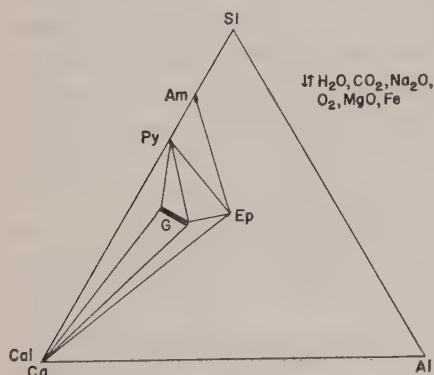
Fig. 8. Paragenesis of zoned skarns found in Shinyama ore deposit.

Key. Am–amphibole, Cal–calcite, Ep–epidote; G–garnet, Py–pyroxene, ⇕– perfectly mobile components.
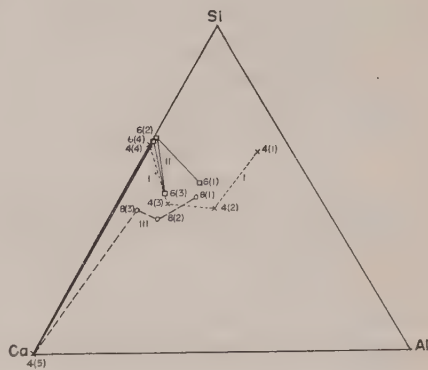
Fig. 9. Chemical composition of zoned skarns and surrounding rocks occurring in Shinyama ore deposit.
Table number and analytical number, shown in round brackets, are also indicated. Solid lines and various kinds of broken lines connect the chemical composition of zoned skarns found in the same locality.

the zoned skarns found in the Shinyama ore deposit are H_2O, CO_2, Na_2O, O_2, MgO, Fe, CaO, SiO_2, Al_2O_3, P_2O_5, and TiO_2. From the paragenetic analysis of minerals constituting zoned skarns, it may be concluded that among these components, the perfectly mobile components participating in the formation of skarns were H_2O, CO_2, Na_2O, O_2, MgO, and Fe, and the rest of the components was inert. All the mineralogical components of the skarns may be represented by a single three component diagram Al-Ca-Si (Fig. 8) prepared upon the basis of observed paragenesis of minerals in zoned skarns, if the accessory apatite and sphene are neglected. In this diagram chemical potentials of H_2O, CO_2, Na_2O, O_2, MgO, and Fe are considered constant. Here, the content of the prefectly mobile components in the constituent minerals of skarns is the function of the ratio of the inert components. However, as the clinopyroxene found in the ore deposit contains only a small amount of aluminum, it was not able to be confirmed that the chemical composition of clinopyroxene is the function of content of aluminum.

The chemical compositions of skarns and surrounding rocks are plotted in Fig. 9 in which their table and analytical numbers are also indicated. In the diagram, solid and dashed lines I, II, and III are drawn corresponding to different cases of metasomatism.

Analysis of formation and growth of zoned skarns

The essence of contact-reaction-metasomatism lies in the diffusion levelling of the pore fluid composition of contrasting rocks with simultaneous adjustment of the rock composition to that fluid. Therefore, the diagrams showing the dependence of mineralogical composition on the chemical potentials of Al, Ca, and Si, i.e. in the scheme of fluid composition, are useful for the comprehension of the formation of zoned skarns. Such a schematic diagram, Fig. 10, is obtained from Fig. 8 by means of formulas drawn from the law of mass action. In these diagrams the components H_2O, CO_2, Na_2O, O_2, MgO, and Fe entering into the minerals of the system are perfectly mobile and their chemical potentials are considered constant. In each diagram, dashed lines I, II, and III are drawn corresponding to different cases of metasomatism. The most common is the case of metasomatism marked by line I, characterized by the following sequence of zones: 1) Epidote-amphibole skarn; 2) Epidote-pyroxene skarn; 3) Garnet-pyroxene skarn; 4) Dark green pyroxene skarn; 5) Marble. The case of metasomatism marked by line II is observed in the skarns replacing a narrow porphyrite dike in limestone, and is characterized by the following sequence of zones: 1) Epidote-pyroxene skarn; 2) Pale green pyroxene skarn; 3) Garnet-pyroxene skarn; 4) Dark green pyroxene skarn; 5) Marble. The case of metasomatism marked by line III is rarely observed, and is characterized by the following sequence of zones: 1) Epidote-amphibole skarn; 2) Epidote-pyroxene skarn; 3) Garnet skarn; 4) Marble. As can be seen from Fig. 10, the formation and growth of contact-reaction-metasomatic zones between limestone and porphyrite occur because of the diffusion of calcium into porphyrite, and of silica and alumina into limestone in the Shinyama

ore deposit. From the continuity in the change of chemical potentials of the diffusing components across the contact, follows the discontinuity of the change of their chemical and mineral composition.
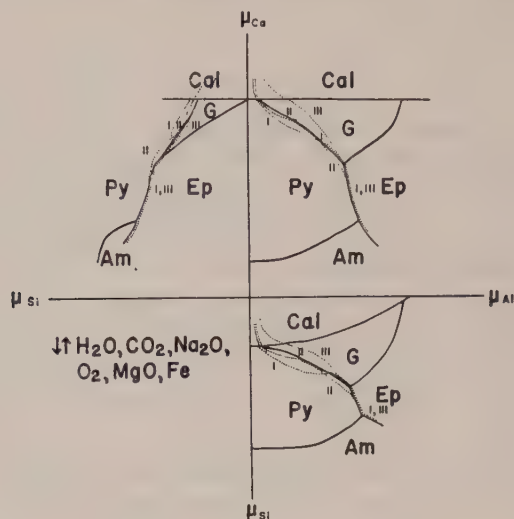
Fig. 10. Chemical potential diagram of the system Al–Ca–Si with perfectly mobile components H_2O, CO_2, Na_2O, O_2, MgO, Fe for zoned skarns found in Shinyama ore deposit.

Key. Am–amphibole, Cal–calcite, Ep–epidote, G–garnet, Py–pyroxene. Dashed lines I, II, and III are drawn corresponding to different cases of metasomatism.

As can be seen from the projections of the potential surface of Turinsk copper ore deposit studied by KORZHINSKY (1948, 1957), the maximum chemical potential for alumina is established at the boundary between the clinopyroxene-plagioclase and clinopyroxene-garnet zones. Therefore, in the Turinsk ore deposit, alumina diffused from there both in the direction of limestone and porphyrite.

The difference in the behavior of alumina during the formation of skarns in the Shinyama ore deposit and the Turinsk ore deposit may have been due to the difference in external conditions during the formation of skarns.

V. Metasomatic phenomena during the formation of paigeite rock

Minerals of the ludwigite series consist of ludwigite and paigeite. The names, ludwigite and paigeite, were given to the mineral with Mg>Fe^{+2} and Fe^{+2}>Mg respectively by PALACHE, BERMAN, and FRONDEL (1951). It was clarified by TAKÉUCHI, WATANABE, and ITO (1950) and TAKÉUCHI (1956) that ludwigite and paigeite are isostructural. From the published chemical composition of minerals of this series (Fig. 11), a complete substitutional series may extend to the end-members. The paragenesis of ludwigite has frequently been described by GEIJER (1927, 1939), WATANABE (1938, 1943), TILLEY (1951),

and others, however, that of paigeite only by the writer (1959). The present section purports to describe the paragenesis of paigeite from the Shinyama ore deposit, to clarify the difference in the parageneses of paigeite and ludwigite, and moreover, to discuss their genesis.
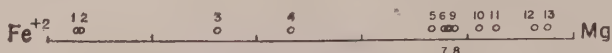
Fig. 11.　Atomic proportions of Fe^{+2} and Mg in minerals of the ludwigite series.

1.　Paigeite.　　Brooks Mountain, Alaska, U. S. A..
2.　Ditto.　　　Kamaishi mine, Iwate Pref., Japan.
3.　Ditto.　　　Riverside, California, U. S. A. (vonsenite).
4.　Ditto.　　　Chersky range, Siberia, U. S. S. R..
5.　Ludwigite.　Hungary.
6.　Ditto.　　　Kilbride, Skye, Great Britain.
7.　Ditto.　　　Hua-Tung-Kou, Feng-Tien Prov. Manchuria.
8.　Ditto.　　　Moravicza, Hungary.
9.　Ditto.　　　Hungary.
10.　Ditto.　　　Hungary.
11.　Ditto.　　　Hol Kol mine, Korea.
12.　Ditto.　　　Lemhi County, Idaho, U. S. A..
13.　Ditto.　　　Hayama mine, Fukushima Pref., Japan.

1.　Paigeite rock and ludwigite-bearing rock

Two modes of occurrence of paigeite are found in the Shinyama ore deposit, namely- 1) paigeite rock occurring as an irregular mass between marble and garnet skarn partly replaced by magnetite; 2) paigeite-bearing impure layers in marble.

Paigeite rock

Paigeite rock is dull black in color and consists of calcite, magnetite, paigeite, phlogopite, tourmaline, and small amounts of apatite, chalcopyrite, chlorite, diopside, pyrrhotite, and sphalerite. The rock is only found at the cross-cut tunnel S40 on the 450 meters-level in the Iron ore body. The rock occurs as an irregular mass reaching 20 meters in diameter between marble and garnet skarn partly replaced by magnetite. Paigeite rock frequently includes kidneys of garnet skarn as shown in Pl. VI, Fig. 1. Locally paigeite rock is seen to cut through garnet skarn along its joints as shown in Pl. VI, Fig. 2. The boundary of paigeite rock to garnet skarn, and that of paigeite rock to marble are sharp. The variation in the paragenesis from paigeite rock to garnet skarn partly replaced by magnetite remains uncertain.

Paigeite rock is poikiloblastic in texture, namely, prismatic crystals of paigeite are embedded in calcite. Apatite, magnetite, phlogopite, tourmaline, and a small amount of diopside are also embedded in calcite (Pl. VII, Fig. 2).

Stout prismatic crystals of apatite reach 1 millimeter in length. Its optical properties are: $\omega=1.641$, $\varepsilon=1.638$, uniaxial negative.

Calcite measures 2 millimeters in diameter. Its optical properties are:

ω=1.658–1.660, uniaxial negative. This mineral has lattice parameters of a_0=4.98 Å, c_0=17.06 Å. Extremely small amounts of iron and manganese were detected by x-ray fluorescence analysis.

Diopside is granular and reaches 0.1 millimeter in diameter. Its optical properties are: α=1.674, γ=1.705, (+)2V=57°, corresponding to 10–15 atomic per cent of $Fe^{+2}/Fe^{+2}+Mg$.

Magnetite is granular and may measure up to about 2 millimeters in diameter. Its lattice parameter is a_0=8.395 Å. An extremely small amount of manganese was detected by X-ray fluorescence analysis, however, no titanium was detected. According to Akimoto, Katsura, and Yoshida (1957) and Basta (1959), these data correspond to almost pure Fe_3O_4.

Paigeite is opaque and reaches 2 millimeters in length. Its optical properties and chemical composition have already been given by Watanabe and Ito (1954). According to their data, the mineral has the composition, $(Fe^{+2}, Mg, Mn^{+2})_2Fe^{+3}BO_5$ with the ratio $Fe^{+2}:Mg:Mn^{+2}$=0.94:0.05:0.01. The mineral is one of the nearest to the iron-rich end-member of the ludwigite series so far as the writer knows.

Phlogopite is flaky and reaches 0.5 millimeter in length. Its optical properties are: β=1.595–1.598, (−)2V$\doteqdot$0°, X= pale yellow, Y= pale green, Z= pale green. An extremely small amount of manganese was detected by X-ray fluorescence studies, however, no titanium was detected. The intensity ratio of (004)/(005) was 0.70–0.85. According to Gower (1957), this ratio corresponds to 40–50 per cent of iron in octahedral sites of phlogopite.

Tourmaline is black in color and may measure up to about 1 millimeter in diameter. Its optical properties are: ω=1.659, ε=1.639, uniaxial negative, O= greenish blue, E= pale brownish pink. Lattice parameters of the mineral are: a_0=15.97 Å, c_0=7.23 Å, c_0/a_0=0.453. An extremely small amount of manganese was detected by X-ray fluorescence analysis. According to Epprecht (1953), these lattice parameters correspond to the tourmaline of dravite-schorlite series.

Peripheries of phlogopite crystals are frequently seen to have been replaced by chlorite. So, chlorite may have been a hysterogenic mineral. Chlorite reaches 0.5 millimeter in diameter. Its optical properties are: β=1.595, (−)2V$\doteqdot$0°, X= colorless, Y= pale yellowish green, Z= pale yellowish green. Paigeite rock is cut by chalcopyrite-pyrrhotite-sphalerite veinlets. These three minerals may have been hysterogenic minerals.

Paigeite-bearing impure layers in marble

Paigeite-bearing impure layers in marble are black in color and consist of calcite, magnetite, paigeite, and small amounts of amphibole, apatite, chlorite, phlogopite, and sphalerite (Pl. VIII, Fig. 1). The impure layers are found at the cross-cut tunnel S100 on the 350 meters-level, and at S200 of the west side tunnel on the 400 meters-level in the Second Copper ore body. The impure layers are found in marble developed near zoned skarns.

Ludwigite-bearing rock from Kamineichi, Iwate Pref.

Two kinds of parageneses of ludwigite were described by WATANABE (1938, 1943) from the Hol Kol mine, Korea, namely-1) calcite-forsterite (or clinohumite)-kotoite-ludwigite-spinel-(suanite); 2) calcite-forsterite (or clinohumite)-ludwigite-magnetite. It was also reported by WATANABE (1954) that a small amount of warwickite is frequently associated with ludwigite.

Recently ludwigite-bearing rock from Kamineichi, the city of Miyako, Iwate Pref. was briefly described by WATANABE (1958). The paragenesis of ludwigite 1) described above is also observed in this rock. Moreover, the following paragenesis is observed: calcite-forsterite (or a mineral of the humite family)-magnetite-phlogopite-spinel. The refractive index of phlogopite is: $\beta = 1.592$. A small amount of warwickite is closely associated with ludwigite. Kotoite is frequently seen to have been replaced by szaibelyite. The paragenesis of suanite is similar to that of kotoite. Szaibelyite may have been hysterogenic mineral. Locally diopside and pargasite are observed in this rock. But their parageneses remain uncertain, because of their rarity.

2. Genetical consideration

As can be seen from the description of paigeite rock, the components constituting paigeite rock are H_2O, CO_2, Na_2O, K_2O, O_2, B_2O_3, Fe, CaO, MgO, SiO_2, and Al_2O_3, and P_2O_5. From the paragenetic analysis of minerals constituting paigeite rock, it may be concluded that among these components, the perfectly mobile constituents participating in the formation of the rock were H_2O, CO_2, Na_2O, K_2O, O_2, and B_2O_3, the rest of the components was inert. In this paragenesis the excess constituents are calcium in the form of calcite, and iron in the form of magnetite. All the mineralogical components of the rock may be represented by a single three component diagram Al-Mg-Si (Fig. 12), if the accessory apatite is neglected. In this diagram chemical potentials of H_2O, CO_2, Na_2O, K_2O, O_2, and B_2O_3 are considered constant. Here, the content of the perfectly mobile components in the constituent minerals of the rock is the function of the ratio of the inert constituents.

As stated before the number of minerals in zoned skarns is one or two, if the accessory apatite and

Fig. 12. Paragenesis of paigeite rock from Shinyama ore deposit.
Key. Cal-calcite, Di-diopside, Mag-magnetite, Pai-paigeite, Phl-phlogopite, Tou-tourmaline, ↕-perfectly mobile components, +-excess components.

sphene are neglected, whereas, that of paigeite rock is five. For this reason it is difficult to consider that paigeite rock was formed during the formation of skarns. Generally speaking, the number of minerals in rocks formed in the earlier stage is small, and that of the later stage is large in contact metasomatic ore deposits. Therefore, paigeite rock may have been formed later than skarns. As the variation in the paragenesis from paigeite rock to garnet skarn partly replaced by magnetite remains uncertain, the age relation of the formation of paigeite rock to that of magnetite also remains uncertain.

As can be seen from the description of ludwigite-bearing rock from Kamineichi, components constituting the rock are H_2O, CO_2, K_2O, O_2, B_2O_3, Fe, MgO, CaO, SiO_2, Al_2O_3, and TiO_2. The paragenetic analysis of minerals constituting ludwigite-bearing rock showed that among these components the perfectly mobile components participating in the formation of the rock were H_2O, CO_2, K_2O, O_2, and B_2O_3, the rest of the components was inert. In this paragenesis the excess constituent is calcium in the form of calcite. All the mineralogical components of the rock may be represented by a single four component diagram Al-Fe-Mg-Si (Fig. 13), if the accessory warwickite is neglected. In this diagram chemical potentials of H_2O, CO_2, K_2O, O_2, and B_2O_3 are considered constant. Here, the content

Fig. 13. Paragenesis of ludwigite-bearing rock from Kamineichi, Iwate Pref..
Key. Cal–calcite, For–forsterite, Kot–kotoite, Lud–ludwigite, Mag–magnetite, Phl–phlogopite, Sp–spinel, $\Updownarrow$–perfectly mobile components, +–excess component.
The joins inside the Si–Mg–Al–Fe tetrahedron or at the bottom of the tetrahedron are shown in broken lines.

of the perfectly mobile components in the constituent minerals of the rock is a function of the ratio of the inert constituents.

In the following consideration, our discussion will be limited to paigeite rock and ludwigite-bearing rock with excess calcium in the form of calcite and excess iron in the form of magnetite. In these rocks the determining inert components are Al, Mg, and Si. With the decrease in the chemical potential of iron, the chemical potential of oxygen must increase, since magnetite is assumed to be an excess mineral. With this decrease, the content of iron in minerals of these rocks must also decrease. It can be seen from the description of paigeite rock that Fe/ Fe+Mg ratios in diopside, phlogopite, and tourmaline constituting paigeite rock from the Shinyama ore deposit are not large, however, that in paigeite is large. As can be seen from the description of ludwigite-bearing rock from Kamineichi, the Fe/Fe+Mg ratio in phlogopite constituting the ludwigite-bearing rock is small. According to WATANABE (1938, 1943), Fe/Fe+Mg ratios in forsterite, ludwigite, and spinel

constituting ludwigite-bearing rock from the Hol Kol mine in the Suan district, Korea are not large.

Of temperature and pressure during the formation of paigeite and ludwigite, nothing is known. However, a rock including ludwigite was found by Knopf and Schaller (1908) in the immediate vicinity in which paigeite rock occurred. Therefore, it is not unreasonable to assume that temperature and pressure during the formation of paigeite and ludwigite were alike.

Assuming, then, a similarity of temperature and pressure during the formation of paigeite and ludwigite, and that chemical potentials of H_2O, CO_2, Na_2O, K_2O, and B_2O_3 were alike, and further that changes in the chemical potential of iron had no effect on the composition of diopside, forsterite, phlogopite, spinel, and tourmaline, but that, they had a striking effect on the composition of the minerals of the ludwigite series, it may be concluded that the paragenesis of paigeite was formed in a condition where the chemical potential of oxygen was low and that of iron was high, whereas, the paragenesis of ludwigite was formed in a condition where the chemical potential of oxygen was high and that of iron was low (Fig. 14).
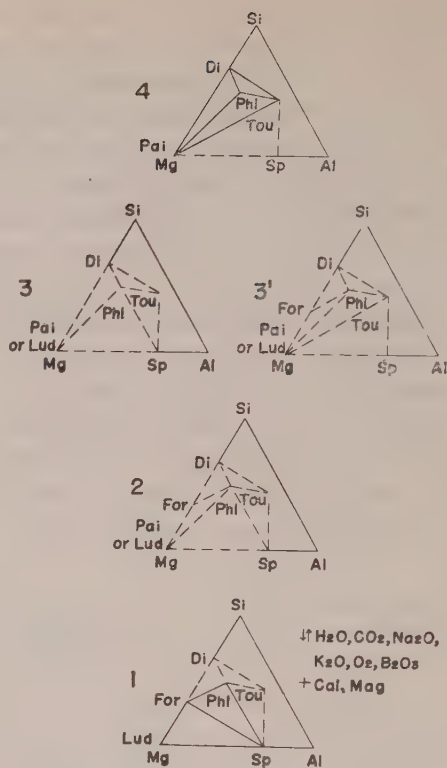
Fig. 14. With increase in the chemical potential of Fe, an expansion of the field of parageneses including the mineral of the ludwigite series takes place in the sequence 1, 2, 3, 4 or 1, 2, 3′, 4. Key. Cal–calcite, Di–diopside, For–forsterite, Lud–ludwigite, Mag–magnetite, Pai–paigeite, Phl–phlogopite, Sp–spinel, Tou–tourmaline, —perfectly mobile components, +–excess components. Solid lines show observed parageneses, and broken lines show assumed parageneses.

VI. Metasomatic phenomena during the formation of ores

The principal ore minerals of the Shinyama ore deposit are magnetite and chalcopyrite.

Garnet skarn with the high andradite molecule, garnet-pyroxene skarn, and dark green pyroxene skarn are frequently replaced by magnetite. Also, dark green pyroxene skarn is often replaced by chalcopyrite associated with pyrrhotite. Indeed, magnetite veins are observed in endo-skarns developed near exo-skarns, and moreover, endo-skarns are partly replaced by magnetite. However, these magnetite veins in endo-skarns and magnetite replacing endo-

skarns may be a negligible quantity as compared with magnetite replacing exo-skarns. In brief, exo-skarns are almost selectively replaced by ore minerals.

In this section the ores found in the Shinyama ore deposit will be described, then, the genetical consideration of them will be discussed.

1. Ores

Magnetite replacing garnet skarn and garnet-pyroxene skarn

Magnetite replacing garnet skarn and garnet-pyroxene skarn is black in color and occurs widely in the Iron ore body.

The ore consists of magnetite reaching 1 millimeter, garnet, pyroxene and small amounts of epidote, calcite, and quartz. However, pyroxene is not found in the magnetite ore replacing garnet skarn. Magnetite often shows auto-morphic outlines against the other minerals, and includes the others frequently. The zonal structure of magnetite was revealed by structural etching. Magnetite within the ore was separated and analysed. Its chemical composition is given in Table 9. The result shows that it is free from TiO_2. These properties are the general characteristics of magnetite found in the ore deposits of the mining district.

Table 9. Chemical composition of magnetite replacing garnet skarn.
Loc. Cross-cut tunnel N140, 400 meters-level, Iron ore body.

	Wt. %	Mol. ratio	Atomic ratios on the basis of O=4	
TiO_2	tr.			
Fe_2O_3	69.40	0.4346	Fe^{+3}	2.013
FeO	29.94	0.4167	Fe^{+2}	0.965
MnO	0.13	0.0018	Mn	0.004
	99.47			

(Anal. H. HARAMURA)

Magnetite replacing dark green pyroxene skarn

Magnetite replacing dark green pyroxene skarn is black in color and is widely developed in the Iron, Second Copper, and Third Copper ore bodies.

The ore is composed of magnetite, pyroxene, and small amounts of amphibole, calcite, and quartz. The grains of magnetite may measure up to about 1 millimeter. The mineral shows automorphic outlines against the other minerals and often includes the others. Magnetite within the ore shows strong zonal structure.

Chalcopyrite and pyrrhotite replacing dark green pyroxene skarn

Chalcopyrite and pyrrhotite replacing dark green pyroxene skarn occur extensively in the Second and Third Copper ore bodies.

The ore consists of amphibole, calcite, chalcopyrite, pyroxene, pyrrhotite, quartz, and small amounts of magnetite and sphalerite. Chalcopyrite and

pyrrhotite measure 0.5–1 millimeter in diameter. A small amount of sphalerite occurs as irregular masses in chalcopyrite and pyrrhotite, and also occurs as star-like masses in chalcopyrite. Again, a small amount of automorphic magnetite is observed in chalcopyrite and pyrrhotite.

Chalcopyrite, " massive cubanite ", and pyrrhotite replacing dark green pyroxene skarn

This ore is grayish yellow in color and is only found at the marble-side of the Second and Third Copper ore bodies. The ore occurring at S300 on the 450 meters-level in the Second Copper ore body will be described below.

It consists of amphibole, calcite, chalcopyrite, cubanite, pyrrhotite, quartz, and small amounts of magnetite, pentlandite, and valleriite. The grains of chalcopyrite, cubanite, and pyrrhotite reach about 1 millimeter.

Chalcopyrite occurs as irregular masses in which small amounts of sphalerite and valleriite are often observed.

Generally speaking, cubanite usually occurs as parallel lamellae within chalcopyrite in many high temperature ore deposits. At the marble-side of the Second and Third Copper ore bodies, a small amount of lamellar cubanite occurs in chalcopyrite. Moreover, a large amount of cubanite occurs as irregular masses against chalcopyrite three-dimensionally. The writer calls such cubanite " massive cubanite " in order to distinguish it from lamellar cubanite. Small amounts of star-like and irregular masses of sphalerite are observed in lamellar cubanite. However, blade-like pentlandite and pentlandite-bearing blade-like pyrrhotite are rarely observed in lamellar cubanite. On the other hand, sphalerite, blade-like pentlandite, and pentlandite-bearing blade-like pyrrhotite are often found in massive cubanite (Pl. VIII Fig. 2).

The blade-like masses of pentlandite are always narrow, having a fairly sharp and smooth boundary with massive cubanite. Two or three sets of parallel blades of pentlandite are often present in the same crystal of massive cubanite. However, there is no enlargement where the blades join. Similarly, the blade-like masses of pyrrhotite are narrow. Two or three sets of parallel blades of pyrrhotite are usually observed in the same crystal of massive cubanite. However, there is no enlargement where the blades join or cross. All parallel blades of pyrrhotite within a crystal of massive cubanite show the same orientation, and cut through the lamellar twinning of massive cubanite. Pentlandite within pentlandite-bearing pyrrhotite blades occurs as small granular grains along the crystal boundary between massive cubanite and blade-like pyrrhotite.

A small amount of magnetite is found as automorphic grains in other minerals.

Pentladite is found as granular masses near the crystal boundaries of pyrrhotite and chalcopyrite or massive cubanite. This pentlandite was separated and confirmed by using an X-ray diffractometer. Its powder pattern is given in Table 10 together with those of pentlandite from Sudbury, Ontario.

Pyrrhotite occurs as irregular masses in which irregular masses of

Table 10.   X-ray powder data of pentlandite

1. MoK$_\alpha$		2. Fe(Mn)		3. Fe			
d(Å)	I	d(Å)	I	d(Å)	I	2θ for FeK$_{\alpha 1}$	hkl
3.54	20	3.54	10	3.55	40	31.68	220
3.34	20	3.34	10				
3.03	90	3.03	70	3.02	100	37.39	311
2.89	70	2.89	40	2.89	60	39.08	222
2.51	10	2.51	10				400
2.30	50	2.30	20	2.30	40	49.82	331
2.09	10	2.095	10				
2.13	10	2.13	10				
1.95	80	1.95	50	1.93	50	60.25	511, 333
1.77	100	1.77	100	1.77	70	66.28	440
1.70	10	1.695	10				
1.53	20	1.525	10				
1.52	20	1.515	10				
1.31	50	1.305	20				
1.25	50	1.25	20				
1.23	20	1.225	10				
1.16	10	1.115	10				
1.07	10	1.069	10				
1.05	10	1.049	10				
1.02	50	1.022	20				

1. Pentlandite from Sudbury, Ontario (A. S. T. M.)
2. Pentlandite from Sudbury, Ontario (G. A. HARCURT)
3. Pentlandite from Kamaishi mine

sphalerite are often observed.

Sphalerite is found as star-like masses in chalcopyrite, lamellar cubanite, and massive cubanite. And sphalerite is also found as irregular masses in chalcopyrite, lamellar cubanite, massive cubanite, and pyrrhotite.

2.   Genetical consideration

Amphibole, calcite, and quartz pseudomorphs after clinopyroxene are frequently observed in dark green pyroxene skarn partly replaced by magnetite or sulphide minerals (Pl. VII, Fig. 1). On the other hand, these pseudomorphs are rarely observed in dark green pyroxene skarn proper. Moreover, no evidence of successive formation is observed among amphibole, calcite, magnetite, quartz, and sulphide minerals. For these reasons, it may be concluded that the formation of skarn minerals was followed by those of amphibole, calcite, magnetite, quartz, and sulphide minerals. A similarity of temperature and pressure during the formation of ores will be assumed in the following discussion.

Paragenesis of minerals in ores

In order to establish the regularities in the parageneses of minerals of a given facies, it is desirable to study as many and as great a variety of parageneses as possible. Especially valuable are samples containing the maximum number of minerals possible for a given facies. For this reason, the paragenesis of minerals of the high grade copper ore containing amphibole, calcite, chalcopyrite, massive cubanite, magnetite, pentlandite, pyrrhotite, quartz, and sphalerite was studied in detail. The paragenesis of minerals of the other ores found in the ore deposit is typified by this paragenesis.

As can be seen from the description given before massive cubanite with blade-like masses of pentlandite and pentlandite-bearing pyrrhotite is thought to be the exsolution product of ferriferous and nickeliferous cubanite solid solution. From the description of chalcopyrite, massive cubanite, and pyrrhotite replacing dark green pyroxene skarn, it can be seen that the components constituting the ore are H_2O, CO_2, S, Na_2O, MgO, O_2, Cu, Ni, Fe, Zn, SiO_2, CaO, and Al_2O_3. In this ore the excess components are alumina in the form of amphibole, calcium in the form of calcite, silica in the form of quartz, and zinc in the form sphalerite. The selection of the determining inert components will be discussed below.

As pyrrhotite found in the ore deposit always includes a small amount of nickel, whereas, magnetite rarely includes nickel, if we select copper, iron, and nickel as the determining inert components, all the mineralogical components of the ore can be represented by a single three component hypothetical diagram Cu-Fe-Ni, in which chemical potentials of H_2O, CO_2, S, Na_2O, MgO, and O_2 are assumed constant. The coexistence of magnetite and massive cubanite, however, can not be explained by this diagram. Oxygen or sulphur must, then, be added to copper, iron, and nickel as the determining inert components. If copper, iron, nickel, and sulphur are selected as the determining inert components, the paragenesis of chalcopyrite-cubanite-pyrrhotite is stable. On the other hand, massive cubanite usually contains blade-like masses of pentlandite and pentlandite-bearing pyrrhotite. Moreover, it was confirmed by X-ray fluorescence analysis that chalcopyrite, pyrrhotite, and massive cubanite excluding blade-like masses of pentlandite and pentlandite-bearing pyrrhotite contain almost the same amount of nickel. From these data, it may be concluded that the

Fig. 15. Paragenesis of high grade copper ores found in Shinyama ore deposit.
Key. Am–amphibole, Cal–calcite, Cp–chalcopyrite, Cub–cubanite, Mag–magnetite, Po–pyrrhotite, Pn–pentlandite, Q–quartz, Sl–sphalerite, ⇕–perfectly mobile components, +–excess components. The joins inside the Cu–Fe–Ni–O tetrahedron are shown in broken lines.

paragenesis of nickel-bearing chalcopyrite solid solution, nickeliferous and ferriferous cubanite solid solution, and nickel-bearing pyrrhotite solid solution was stable in the Shinyama ore deposit during the formation of ores. This conclusion is well interpreted by selecting copper, iron, nickel, and oxygen as the determining inert components. Hence, all the mineralogical components of ores may be represented by a single four component diagram Cu-Fe-Ni-O (Fig. 15), in which chemical potentials of H_2O, CO_2, S, Na_2O, and MgO are considered constant. Here, the content of the perfectly mobile components in the consitituent minerals of ores is a function of the ratio of the inert components.

Zonal distribution of ores

From the porphyrite-side to the marble-side, the following zonal distribution of ores is observed in the Second Copper ore body: 1) magnetite replacing garnet-pyroxene skarn or dark green pyroxene skarn; 2) chalcopyrite and pyrrhotite replacing dark green pyroxene skarn; 3) chalcopyrite, massive cubanite, and pyrrhotite replacing dark green pyroxene skarn.

The zonal distribution of magnetite and sulphide minerals is interpreted as follows: oxygen may, as stated before, have been perfectly mobile during the formation of skarns, while, it may have been inert during the formation of ores. Therefore, the chemical potential gradient of oxygen may have been formed in the skarn zones during the formation of ores, because of the difference in the oxygen content in garnet and clinopyroxene. Thus, garnet-pyroxene skarn or dark green pyroxene skarn adjacent to garnet-pyroxene skarn may have been replaced by magnetite, while, dark green pyroxene skarn developed near marble may have been replaced by sulphide minerals.

The high iron content in the sulphide ore developed near marble is explained as follows: the hedenbergite molecule in pyroxene, as stated before, increases from the porphyrite-side to the marble-side gradually. Furthermore, as also stated before, iron may have been perfectly mobile during the formation of skarns, while, it may have been inert during the formation of ores. Therefore, dark green pyroxene skarn with a high content of iron developed near marble may have been replaced by the sulphide ore with a high content of iron.

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A. Tsusue

Contact Metasomatic Iron and Copper Ore Deposits of the Kamaishi
Mining District, Northeastern Japan

Plate V

Fig. 1. Photograph showing the mode of occurrence of skarns.

Key. B-biotite-rich altered porphyrite, dPv-dark green pyroxene vein, E-epidote skarn, Ev-epidote vein, GP-garnet-pyroxene skarn, Gv-garnet vein, S-sericitized porphyrite. Loc. Sub-level, S90, 450 meters-level, Second Copper ore body, Shinyama ore deposit.

Fig. 2. Photograph showing the mode of occurrence of skarns.

Key. Av-axinite vein, dPv-dark green pyroxene vein, EP-epidote-pyroxene skarn, Ev-epidote vein, GP-garnet-pyroxene skarn, Gv-garnet vein, pP-pale green pyroxene skarn. Loc. Cross-cut tunnel S110, 450 meters-level, Second Copper ore body, Shinyama ore deposit.

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2

A. Tsusue

Contact Metasomatic Iron and Copper Ore Deposits of the Kamaishi
Mining District, Northeastern Japan

Plate VI

5 cm

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2

A. Tsusue

Contact Metasomatic Iron and Copper Ore Deposits of the Kamaishi
Mining District, Northeastern Japan

Plate VII

Explanation of Plate VII

Fig. 1. Photomicrograph showing the clinopyroxene partly replaced by amphibole, calcite, and quartz.

 Key. A-amphibole, C-calcite, P-clinopyroxene, Q-quartz. Loc. Cross-cut tunnel S110, 450 meters-level, Second Copper ore body, Shinyama ore deposit.
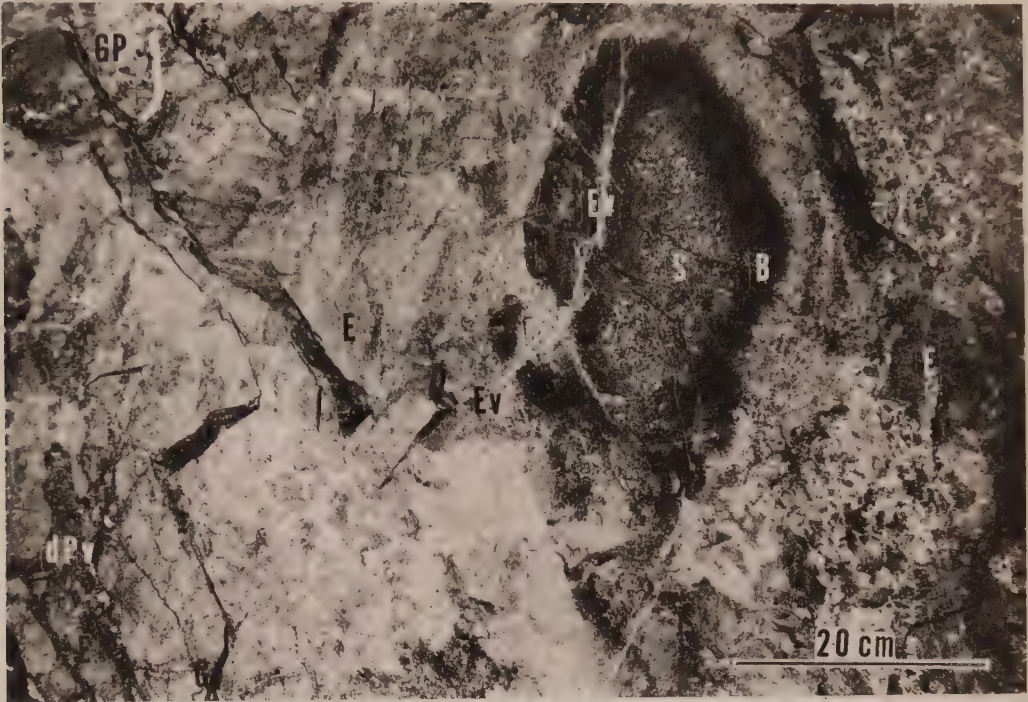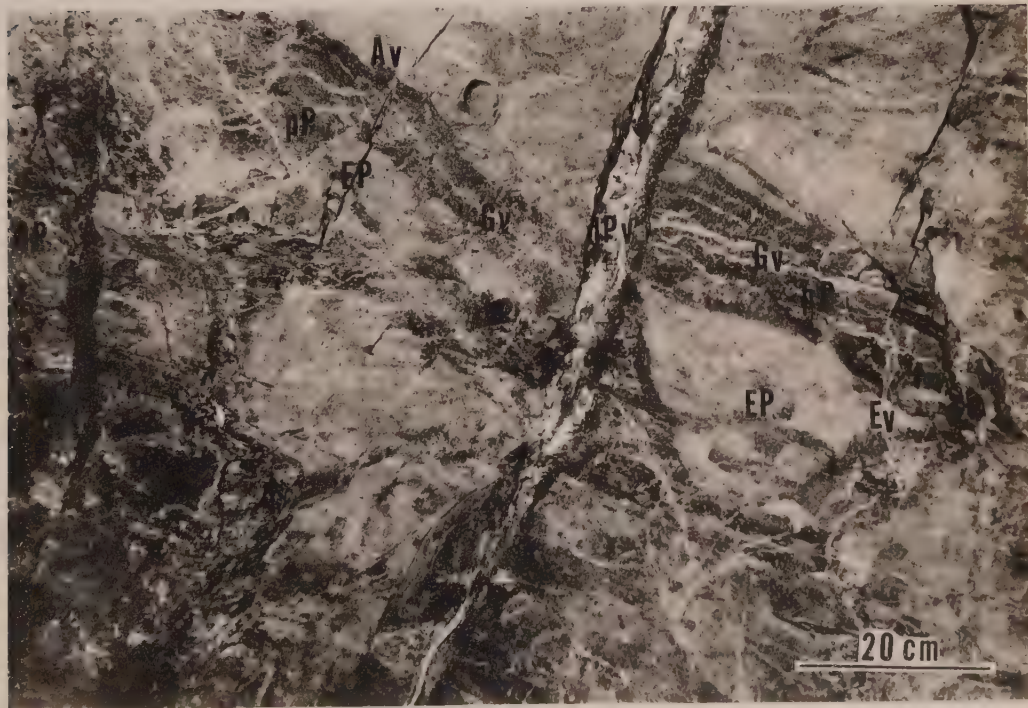
Fig. 2. Photomicrograph of a thin section of paigeite rock.

 Key. C-calcite, M-magnetite, P-paigeite, Ph-phlogopite, T-tourmaline. Loc. Sub-level, cross-cut tunnel S40, 450 meters-level, Iron ore body, Shinyama ore deposit.
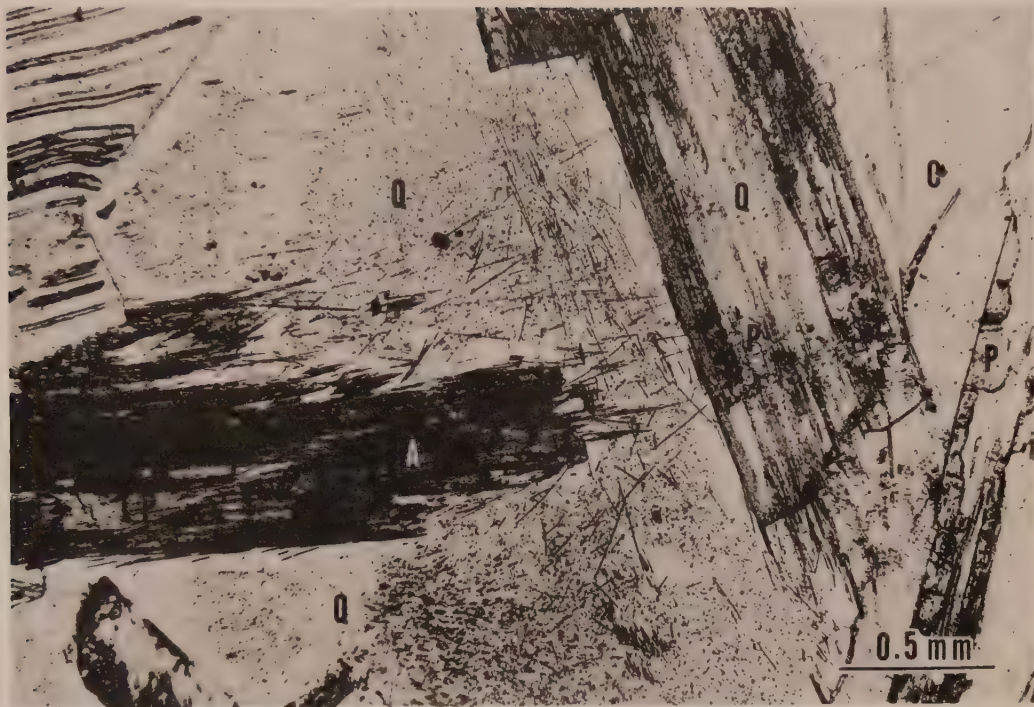
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A. Tsusue

Contact Metasomatic Iron and Copper Ore Deposits of the Kamaishi
Mining District, Northeastern Japan

Plate VIII

Explanation of Plate VIII

Fig. 1. Photomicrograph of a thin section of paigeite-bearing impure layers in marble.
Key. C-calcite, M-magnetite, P-paigeite, S-sphalerite. Loc. Cross-cut tunnel
S100, 350 meters-level, Second Copper ore body, Shinyama ore deposit.

Fig. 2. Photomicrograph of a polished section showing blade-like pentlandite and
pentlandite-bearing blade-like pyrrhotite in " massive cubanite ".
Key. C-cubanite, Cp-chalcopyrite, G-gangue minerals, P-pyrrhotite, Pn-pentlandite.
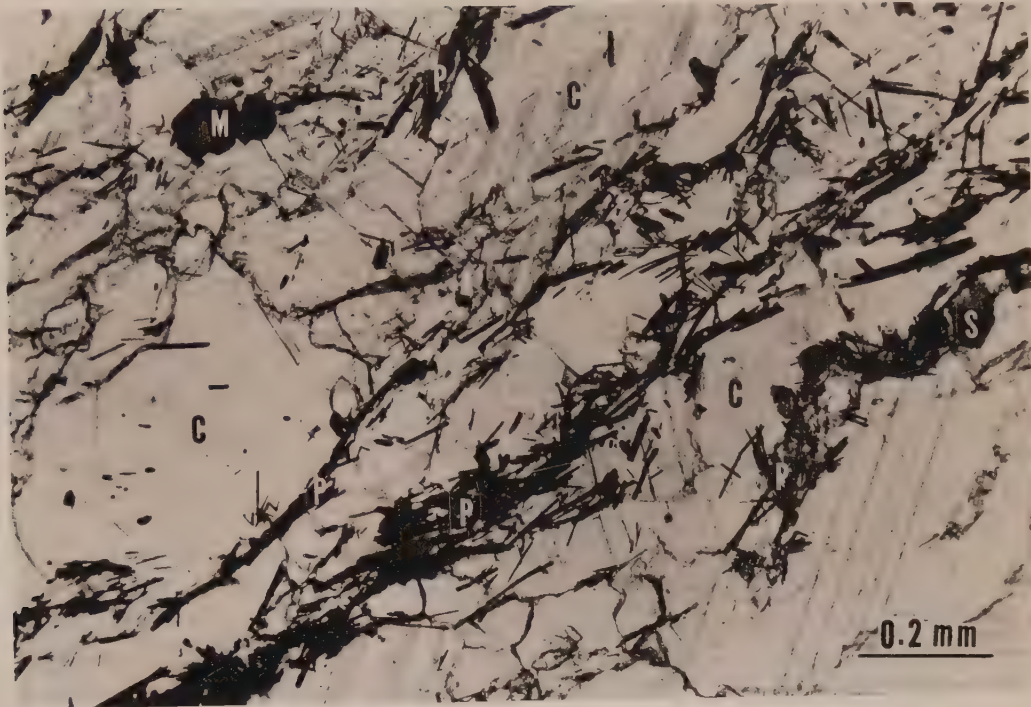
1
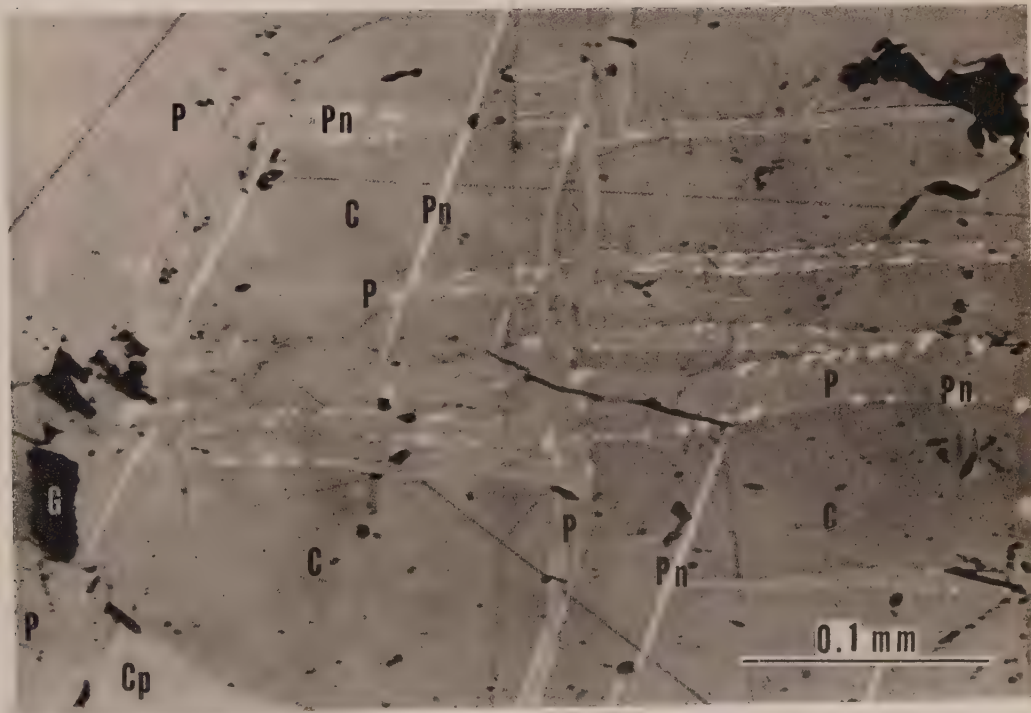
2

THE CAMBRO-ORDOVICIAN FORMATIONS AND FAUNAS OF SOUTH KOREA PART VIII

PALAEONTOLOGY VII

Cambrian Faunas of the Mun'gyong (Bunkei) District and the Samposan Formation of the Yŏngwŏl (Neietsu) District

By

Teiichi KOBAYASHI

With Plates IX–XIII

Introductory Notes

The major part of fossils described in this part was obtained from the Bunkei zone or the median belt of the Mun'gyong district. It lies in the southeastern prolongation of the Seizen or Chongson zone of the Kangwondo (Kogendo) limestone plateau where the Chosen group is quite unfossiliferous. In the Mun'gyong district, however, the lower part of the group yields the *Redlichia*-bearing Mantoan fauna more abundantly than any other place in South Korea. Beside the *Redlichia* shales there are limestones containing the *Palaeolenus*, *Ptychoparia*, *Kootenia* and *Nisusia* faunules.

Fossils of the Kanairi or Hanaeri formation of the Bunkei or Mun'gyong zone are, though the number of species is small, very interesting because they show close alliance to the Masari faunas of Neietsu or Yŏngwŏl zone which are to be described in the next part.

In the Yŏngwŏl zone the Samposan formation which underlies the Masari formation is the oldest. It is not very fossiliferous, but fortunately a small number of Middle Cambrian fossils were procured from shale and sandstone of the Samposan formation.

The fossils of the Samposan or Sambangsan formation as well as those of the Mun'gyong district are not well preserved. Many of them are badly deformed. Nevertheless they are valuable, because these faunas are quite new for South Korea. Naturally they contain some new species and genera.

On this occassion the Redlichiida and some families and genera of the Corynexochida and Ptychopariida are discussed with special reference to Asiatic forms. For the comparative study of the redlichioids it was a great help for me to have had the happy opportunities in 1952 to see the Lower Cambrian formations in the Anti-Atlas, Marocco and in Spain and to make fossil collections at Amouslek on the Sous and Alanis and Cala in Andalusia.

The fossils dealt with in this part were collected by Messrs. T. SHIRAKI,

H. Amano, I. Yosimura and K. Aoti beside myself. Here I wish to record my sincere thanks to these geologists for the fossil collections, to Dr. J. Marçais, Prof. L. Neltner, Dr. R. Ambroggi, Prof. M. San Miquel de la Camara, late Dr. P. Hernandez Sampelayo and Prof. B. Melendez for the courtesies and assistances for travelings in these countries, to Mr. Z. Konishi for translation of Russian references and to Messrs. C. Ueki, S. Suzuki and T. Ichikawa for their assistances in preparation of this manuscript.

Contents

I. Cambrian Fossils from the Mun'gyong District

The sedimentary complex is distributed in the district in three tectonic belts separated by thrusts (KOBAYASHI and AOTI, 1942). In the northwestern or Hakkwasan belt it is so highly metamorphosed that it was considered Pre-Cambrian. The southeastern or Shinkiri belt occupies the southwestern extension of the southern wing of the Paek'unsan or Hakuunsan syncline. It is composed of the Daido Series, Heian group and the Chosen group. The sequence of the last is the Tuwibong or Tsuibon type as can be recognized by its lithology.

The Chosen group is extensive in the median or Mun'gyong belt, beside the Heian group and Daido series which form small structural basins. The Chosen group of this belt consists of six formations in descending order as follows:

6. Todon or Tot'am formation, no less than 300 m. thick, containing the Tsuibon fauna in the upper part (1958)
5. Teiri or Chŏngni banded limestone, about 300 m. thick.
4. Sekkyori or Sŏkkyori limestone and marl alternation, about 200 m. thick.
3. Kanairi or Hanaeri limestone and slate alternation, about 150 m. thick, yielding *Amphoton*, *Hedinaspis* and other fossils.
2. Majo or Masong limestone and shale, about 100 m. thick, containing *Kootenia*, *Nisusia*, *Ptychoparia* and *Palaeolenus* limestones.
1. Kuro or Kurang *Redlichia* shale.

Cut by faults, the base of the Chosen group is unexposed in this belt.

Cambrian fossils of the belt were collected by SHIRAKI, AMANO, AOTI and myself, all in Masŏng-myŏn, Mun'gyong-kun, Kyŏngsang-bukto. (慶尚北道聞慶郡 麻城面). Locality numbers of AMANO and AOTI are marked respectively with Am and N; those of SHIRAKI with Ma or Kan. Jointly with AOTI I examined the stratigraphic relation among these localities in the fie d.

(1) Am 271, Am. 274, N 1, N 7, Ma 13 and Kan 1 are in the same *Redlichia* shale beds at Kurang-ni (九郎里) bent of the Yonggang (穎江), (8 in fig. 1.)
(2) Ma 24 and Ma 25 are on the right bank and Ma 26 on the left bank of the Yonggang adjacently below the Kurang-ni bent, (9 & 10 in fig. 1.)
(3) Am 272, Am 273-A & B, Am 276, N 2, Ma 23, Ma 32 and Kan 2-A & B are all at Taebang-san (待方山) cliff, (7 in fig. 1.), but in different horizons among which the following four can be distinguished;
    Nisusia limestone (Am 272, Ma 32)
    Kootenia limestone (Am 273-A. N 2, Ma 23, Kan 2-A)
    Ptychoparia limestone (Am. 275, Am. 276)
    Palaeolenus limestone (Am 273-B, Kan 2-B)
(4) N 3 and Kan 3 are at Arakol (6 in fig. 1.) near Hanae-ri (下乃里) where fossils occur in some horizons of the Kanairi formation.
(5) Exact points of localities are unknown of Am 277. and Ma 18.

Beside Ordovician fossils which were collected at Kan 4, Kan 6 and Lower Kan in the Mun'gyong belt, there is *Lingula* sp. (Plate V, Figure 24) from Kyont'al-li which is a solitary fossil in the Sin'giri or Shinkiri belt of the Mun'gyong district.

AMANO's collection
    Am 271. *Redlichia* shale at Kurang-ni bent.
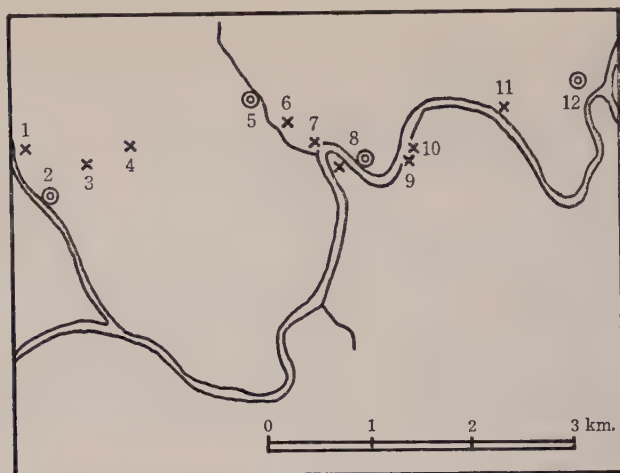   *Redlichia nobilis* WALCOTT

Figure 1. Cambro-Ordovician Fossil Localities in
the Bunkei or Mun'gyong Belt.

1. Kan 6.
2. Tot'am-ni (都吞里).
3. Lower Kan.
4. Kan 4.
5. Hanae-ri (下乃里).
6. Arakol; N 3, Kan 3.
7. Taebang-san (待方山); Am 272, Am 273 A & B, Am 275,
    Am 276, N 2, Ma 23, Ma 32, Kan 2 A & B.
8. Kurang-ni (九郎里) bent; Am 274, N 1, Ma 13, Kan 1.
9. Ma 24.
10. Ma 25.
11. Ma 26.
12. Pongsaeng-dong (鳳笙洞).

Am 272. *Nisusia* limestone at Taebang-san cliff.
         Nisusia paucicostellata KOBAYASHI, new species.
         Hampilia goniospira KOBAYASHI
         Kootenia amanoi KOBAYASHI, new species
         Amphoton spicula KOBAYASHI
         Mungyongia tulipiformis KOBAYASHI, new gen. and species
Am 273-A. *Kootenia* limestone at Taebangsan cliff.
         Kootenia amanoi KOBAYASHI, new species
Am 273-B. *Redlichia* limestone at the same cliff as the preceding.
         Redlichia sp.
Am 274.   *Redlichia* shale at Kurang-ni bent.
         Redlichia nobilis WALCOTT
Am 275. *Ptychoparia* limestone at Teibangsan cliff.
         Eodiscid indt.
Am 276. *Ptychoparia* limestone at Taebangsan cliff.
         Dawsonia bunkeiensis (KOBAYASHI)
         Dawsonia bunkeiensis var. *sulcatus* (KOBAYASHI)
         Ptychoparia aff. *impar* WALCOTT
Am 277. *Redlichia* limestone; exact locality unknown.
         Redlichia sp.

AOTI's collection
>   N 1. *Redlichia* shale at Kurang-ni bent.
>   *Redlichia nobilis* WALCOTT
>   N 2. *Kootenia* limestone of Taebangsan
>   *Kootenia amanoi* KOBAYASHI, new species
>   N 3. Kanairi formation at Arakol near Hanae-ri
>   *Obolus* sp.
>   *Acrotreta* sp.
>   *Pseudagnostus primus* KOBAYASHI
>   *Hediniaspis* cfr. *regalis* (TROEDSSON)
>   *Manchuriella* sp.
>   *Proceratopyge* (*Lopnorites*?) sp.
>   N 7, *Redlichia* shale at Kurang-ni
>   *Redlichia nobilis* WALCOTT

Green phyllitic slate of Chikunsan shale at Kyont'al-li, Hot'al-myŏn, Mungyong-gun.
(閒慶郡虎灘佳面犬灘里地方).
>   *Lingula* (?) sp. indet.

SHIRAKI's collection
>   Ma 12. *Ptychoparia* zone in the south of Hanae-ri.
>   *Dawsonia bunkeiensis* (KOBAYASHI)
>   *Dawsonia bunkeiensis* var. *sulcatus* (KOBAYASHI)
>   *Ptychoparia* aff. *impar* WALCOTT
>   Ma 13. *Redlichia* shale at Kurang-ni bent.
>   *Redlichia nobilis* WALCOTT
>   Ma 18. *Hyolithes* sandstone at Taebangsan
>   *Hyolithes* sp.
>   Ma 23. *Kootenia* limestone at Taebangsan
>   *Kootenia amanoi* KOBAYASHI, new species
>   *Amphoton* cfr. *spinula* KOBAYASHI
>   Ma 24. *Redlichia* limestone on the Yonggang bank, east of Kurang-ni.
>   *Redlichia* sp.
>   Ma 25. *Redlichia* limestone above Ma 24.
>   *Redlichia* sp.
>   Ma 26. *Palaeolenus* zone at Pongsang-dong (鳳筌洞) on the Yonggang bank.
>   *Redlichia* cfr. *cylindrica* CHANG
>   *Palaeolenus aotii* KOBAYASHI, new species
>   Ma 32. *Nisusia* limestone at Taebangsan cliff.
>   *Nisusia paucicostellata* KOBAYASHI, new species
>   *Hampilia goniospira* KOBAYASHI, new species
>   *Amphoton spinula* KOBAYASHI
>   *Mungyongia subovalis* KOBAYASHI, new gen. and species
>   Pisolitic limestone.
>   Kan 1. *Redlichia* shale at Kurang-ni bent.
>   *Redlichia nobilis* WALCOTT
>   Kan 2a. *Kootenia* limestone, north of Taebangsan.
>   *Kootenia amanoi* KOBAYASHI, new species
>   Kan 2b. *Redlichia*-bearing calcareous shale at Taebangsan.
>   *Redlichia chinensis* WALCOTT
>   Kan 3. Kanairi formation at Arakol southeast of Hanae-ri.
>   *Pseudagnostus primus* KOBAYASHI
>   *Amphoton microlops* KOBAYASHI
>   *Ptychoparia* sp.
>   *Anomocarella* sp. indt.

II. Middle Cambrian Fossils from the Samposan Formation

This formation occupies the lowest part in the Yŏngwŏl or Neietsu type of the Cambro-Ordovician sequence. Its base is unexposed, because it thrusts itself on the Heian group. Two fossil zones were found by YOSIMURA in it. The lower one is in green slates at locality 310 west of Yongjon-dong or Ryudendo (竜田洞) and contains a few fossils which are all badly deformed and poorly preserved. Nevertheless, they are tried to determine their taxonomic positions. As the result *Yabeia* sp. indt., *Haniwoides* (? sp. indt. and an indeterminable thoracic segment are distinguished among them.

The sandstones at locs. 314, 316 and 317 represent the upper or *Metagraulos sampoensis* zone. The localities and fossils therefrom are as follows:

Loc. No.	314	316	317
Obolid, gen. and sp. indt.			×
Acrotreta sp. indt.			×
Metagraulos sampoensis KOBAYASHI, new species	×	×	×
Megagraulos semicircularis KOBAYASHI, new species			×
" *Ptychoparia* " sp. indt.		×	×
Solenoparia (?) *bisulcata* KOBAYASHI, new species		×	
Anomocarella stenorachis KOBAYASHI, new species			×

Loc. 314: South slope of Sambang-san or Mt. Sampo (三方山) near the summit.
Loc. 316: A boulder found at Toma-ch'l or Dobaji (道馬峙).
Loc. 317: Midway between Toma-ch'l and Ch'ondong-ni or Sendori (泉洞里).

III. Description of Fossils

Here the taxonomy of the Redlichiida and Corynexochida are discussed in some detail, paying special attention to the Asiatic families, genera and species. It is certainly a remarkable fact that the Corynexochida represent a much greater group of trilobites than thought before, which have most flourished in Asia and especially in North Asia.

One genus and 10 species established through this paper are as follows:

Mungyongia
Anomocarella stenorachis
Kootenia amanoi
Megagraulos (?) *semicircularis*
Metagraulos sampoensis
Mungyongia subovalis
Mungyongia tulipiformis
Nisusia paucicostellata
Palaeolenus aotii

Redlichia paucisegmenta
Solenoparia (?) *bisulcata*

Brachiopoda

Genus *Lingula* BRUGUIÈRE, 1902

Lingula (?) sp.

Plate XII, Figure 24.

A poorly preserved ventral (?) valve resembles *Lingula* sp. indt. from the Chikunsan shale of Saishori (1935) in size and outline. This is a solitary fossil so far known from the Chosen group in the Tsuibon zone of the Mun'gyong distinct. Stratigraphically, the slate which yielded the brachiopod takes the place of the Chikunsan shale.

Occurrence:—Tan- coloured phyllitic slate at north of Kyont'al-li, Mun'gyong-kun, Kyongsang-bukto.

Obolid, gen. and sp. indt.

Shell about 7 mm. wide and 8.5 mm. long, suboval and gently convex. Tubercles scattered on the cast suggest that the inner side of the shell is pitted. The bad state of preservation makes its exact determination difficult.

Occurrence:—This is a solitary brachiopod of the Samposan formation found in the *Metagraulos* zone at loc. 317.

Genus *Nisusia* WALCOTT, 1905

Nisusia paucicostellata KOBAYASHI, new species

Plate XII, Figures 6–7.

Shell subquadrate and biconvex; hinge margin straight, representing the greatest width of shell and forming a right angle with a lateral margin. Ventral valve with a median sinus which is shallower than that of *Nisusia cooperi*. Radial ribs are much stronger and smaller in number than those of *N. cooperi*. Interior of ventral or dorsal valve very simple; two long muscle scars divergent in the latter.

Occurrence:—*Nisusia* limestone at Ma 32.

Mollusca, Gastropoda

Family Helcionellidae WENZ, 1938

Subfamily Hampilininae KOBAYASHI, 1958

Genus *Hampilina* KOBAYASHI, 1958

Hampilina goniospira KOBAYASHI, 1958

Plate XII, Figures 23a–b.

1958. *Hampilina goniospira* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 29*, p. 115, pl. VIII, figs. 1a–c, 2.

The species and genus were described in detail in my recent paper. Attention was called for its septate structure in the apical portion. The illustration shows the broken apex at a septum, sharp angulation between the outer and lateral walls and transverse ridges on the walls.

Occurrence:—Ma 32, 272.

Arthropoda, Trilobita

Order Agnostida KOBAYASHI, 1939

Suborder Eodiscina RAYMOND, 1931

Family Eodiscidae RAYMOND, 1931

Genus *Dawsonia* HARTT in DAWSON, 1868

Dawsonia bunkeiensis (KOBAYASHI)

Plate XII, Figures 15-17.

1942. *Pagetia (Eopagetia)* sp. nov. KOBAYASHI and AOTI, *Proc. Imp. Acad. vol. 18*, p. 305, (Listed).
1943. *Metadiscus bunkeiensis* KOBAYASHI, *Ibid. vol. 19*, p. 41, figs. 1, 3, 5.
1944. *Metadiscus bunkeiensis* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, sec. 2, vol. 7, pt. 1*, p. 74.

In a cephalon in fig. 15 the crenulation on the marginal border is emphasized by lateral compression. The occipital spine looks long in it, but in another in fig. 17 the neck ring is simply thickened in the middle. The pygidium in fig. 16 has no tubercle on the axial rings. It is bordered by a narrow rim.

Occurrence:—Ma 12.

Suborder Agnostina SALTER, 1864

Family Pseudagnostidae WHITHOUSE, 1936

Genus *Pseudagnostus* JAEKEL, 1906

Pseudagnostus primus KOBAYASHI

Plate XII, Figures 20 and 21

1935. *Pseudagnostus primus* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 108, pl. 14, figs. 6-10.
1939. *Pseudagnostus primus* KOBAYASHI, *Ibid. Sec. 2, Vol. 5, Pt. 5*, p. 158.

The cephalon has a trilobed glabella with a median tubercle crossing the posterior furrow and a longitudinal preglabellar furrow. Only the anterior lobe of the axis is distinctly outlined on the pygidium, which narrows backward. A median tubercle lies on the posterior part of the lobe. The marginal border is relatively thick and the lateral spine absent.

Occurrence:—Division 3 of Kanairi formation; Kan. 3.

Order Redlichiida Richter, 1933

A term, "archaepygidium" was proposed in 1954 for a small pauci-segmented pygidium of the polymenic trilobites. It is more or less quadrate and largely occupied by the axial lobe and the pleural lobes are not well developed. The archaepygidium is typically represented in olenellids, redlichiids and some other archaeic trilobites.

Stubblefield (1926) has shown with *Shumardia pusilla* that a production of a new segment takes place at the anal segment. *Redlichia chinensis* provides an interesting example for the polymerism i. e. the increase of thoracic segments which takes place by the migration of an anterior semianchylosed segment of the pygidium into the thorax (Kobayashi and Kato, 1951). Such a segment was found by Öpik (1958) to exist also in *Redlichia forresti* (Etheridge) in Australia.

In the Redlichioid-trilobites the polymerism occurs simultaneously with the production of a new segment in the growth zone with the result it occurs that the archaepygidium is maintained until the full maturity. However, if the polymerism ceases before the cessation of the metamerism, the pygidium becomes multisegmented and larger than the archaepygidium. For example, Lower Cambrian *Lancastria* indicates the primitive stage and its later development is represented by Middle Cambrian *Oryctocephalus*. The former has an archaepygidium and 18 segments in thorax, but in the latter the pygidium is multisegmented and its pleural lobes are well developed. Its thoracic segments are reduced to 12. The cephalon of *Oryctocephalus* is, however, essentially the same as that of *Lancastria*.

In 1952 when I had an opportunity to study the collection of the Geological Survey at Rabat I was strucked by the fact that no redlichioid of Morocco has an archaepygidium (1954). This agreed with my field observations at Amouslek on the Sous valley and also at Alanis in Andalusia. Therefore I was led to the contention that the redlichioids of Spain and Morocco are morphologically more advanced than Asiatic *Redlichia*.

It was in 1940 that R. and E. Richter have denominated *Saukianda* for a Spanish trilobite genus with the thought that its type-species is an Upper Cambrian saukid of Andalusia, but its close relationship with redlichiids is now generally accepted. Since Wilson (1948) has discussed its age, the *Saukianda* fauna is considered Lower Cambrian.

The type-species, *Saukianda andalusia* R. and E. Richter, has a very strong posterior and occipital furrow and granulose test. The authors' pygidium of the species is multisegmented and has so well developed pleural lobes and a marginal border as those of *Perrector perrectus* and *Resserops resserianus*, while Henningsmoen (1957) has referred an archaepygidium to this species.

Saukianda is so intimately related to *Pseudosaukianda* Hupé and *Longianda* Hupé from Morocco that Henningsmoen united them into a single genus. Compared to *Saukianda* and *Longianda* the anterior facial sutures are more

widely divergent in *Pseudosaukianda*. In *Longianda* the glabella is distinctly contracted near the posterior furrows, while it is parallel-sided or slightly expanded backward in the two others. These differences are not very great and their evaluation to be generic or specific is a matter of opinion. At any rate they indicate as a whole a branch of the Redlichiacea which is known by the name of Saukiandidae HUPÉ. It is ascertained that *Longianda termieri* HUPÉ has 14 or 15 segments in thorax and its pygidium is not redlichioid but has broad pleural lobes and a margimal border.

I agree with HENNINGSMOEN in the opinion that *Perrector perrectus* and *Resserops resserianus* were created by R. and E. RICHTER respectively on the basis of a laterally and longitudinally compressed form of an identical species, where the former specific name possesses the page priority. *Eops eo* of the authors, insofar as the cranidium (Taf. 2, Fig. 46) is concerned, seems to be founded on still another deformed specimen of the same species whose anterior outline is obscure.

HUPÉ erected two subgenera *Richterops* and *Rawops* with *Resserops* (*Richterops*) *falloti* and *Resserops* (*Rawops*) *dubius* from Morocco, but they are not very distinct from *Resserops*. It is a remarkable fact that *Despujolsia rochi* HUPÉ is macropleural at the fourth thoracic segment counted from the rear side, as it is in *resserianus* and *falloti*. *D. rochi* is, however, different from the two others in possession of tiny spines on the periphery of the pygidium, constriction of the glabellar outline and the forward thickening of the palpebral lobes, although the latter two features may be due to the secondary deformation to a certain extent. I think *D. rochi* to represent a good genus, but it may be too far going to isolate it from the two others in the family rank. The Despujolsiidae HARRINGTON may be accepted to include *Despujolsia*, *Perrector* and some other genera probably including *Clariondia* and *Pareops*. The pygidium referred to *Clarondia* belongs to the same kind with that of *Perrector*.

Gigantopygus HUPÉ is allied to the precedings in the cephalon but quite different from them in the elongate pleurae of the thorax and pygidium. The palpebral lobes are strongly curved and decurrent along the anterior part of the glabella. The cranidium and glabella are much broader in this than in *Neoredlichia*. It can hardly be overlooked that *Neoredlichia latigene* HUPÉ agrees better with *Gigantopyge* and *Neoredlichia* in these aspects of the cranidium. It is quite probable that *N. latigene*-like form can be produced from *Marsaisia* by the sagittal compression of the cranidium. The pygidium of the Gigantopygidae is remarkably elongated and has two long flat posterior spines.

The Andalusiidae, Despujolsiidae and Gigantopygidae are three redlichioid branches in the western Mediterranean province which are morphologically more advanced than *Redlichia*. Whether or not the trilobites' cranidia in Morocco and Eastern Asia which are referred to *Neoredlichia* or *Pararedlichia* are congeneric cannot be decided until their complete shields or at least their pygidia will be found.

Family Redlichiidae Poulsen, 1927

Diagnosis:—Polymeric opisthoparian trilobites with long, cylindro-conical glabella, large semi-circular palpebral lobes and eye-ridges, the posterior ends of which are close-set to the glabella, widely divergent anterior facial sutures issuing from the vicinities of the glabella, long genal spines, multisegmented thorax, and small pygidium with paucisegmented broad axial lobe. Intergenal angles often district.

Remarks:—As Etheridge (in Foord, 1890) has called a Redlichian form as *Olenellus* (?) *forresti*, *Redlichia* is certainly similar to the Olenellidae in many features, but the presence of the opisthoparian facial suture is the faundamental difference. Beside *Olenellus*, Redlich (1899) brought *Protolenus, Paradoxides* and *Metadoxides* into comparison with his *Hoeferia*, i. e. *Redlichia*. They are all considered now important members of the Redlichiida. In addition, Walcott (1905) called attention to its close resemblance with *Zacanthoides* which looks a redlichiid or a dolichometopid in some or other aspects.

Emphasizing the close resemblance of *Redlichia* with the Mesonascidae or Olenellidae, Poulsen proposed the Redlichiidae which was subsequently combined with the Mesonascidae and Paradoxidae in the Redlichiidea by Richter (1932). Lately the Ellipsocephalidae and Protolenidae were added to and the Olenellidae were eliminated from the superfamily by Henningsmoen (1951). The superfamily, Redlichioidae, were classified by Hupé (1952, 53) into 14 families including the Bathynotidae, Hicksidae, and Yinitidae, but the Bathynotidae are evidently so distinct that the family is distinguished as the Bathynotina in the *Treatise on Invertebrate Paleontology* (1959).

The protaspids of *Redlichia chinensis* (Kobayashi and Kato, 1951), " *Redlichia* " *intermedia* (Lu; 1940), *Palaeolenus deprati* (Lu, 1942), and *Lusatiop* or *Wutingaspis* sp. (Chang, 1953) are allied to one another. They are all subovate or subelliptical shields with entire margins; axial lobe tapering gradually backwards, quinquisegmented; frontal lobe very large. Eye-ridges are well developed in *intermedia* and *deprati*. They as a whole reveal close resemblances with protaspids of *Dolerolenus* (Bornemann, 1891) and also of *Paradoxides pinus* (Westergaard, 1936) and *Blackwelderia quadrata* (Endo, 1935) in the same stage. They are quite different from the larval forms of *Paedeumias hanseni* (Poulsen, 1932) as well as *Elliptocephala asaphoides* (Walcott, 1889) which used to be considered protaspids, but Whittington (1957) pointed out that they are early meraspids. The difference of early ontogeny combined with the presence or absence of the facial sutures most probably means the divergence between the Redlichiidae and Olenellidae to be wide.

The Protolenidae are different from the Redlichiidae primarily in the palpebral lobe and eye-ridge describing a quarter of a circle or typically more or less rectangular and widely apart from the glabella at the posterior end. Insofar as the cephalon is concerned, the meraspids of *chinensis* and *intermedia*

are very similar to mature protolenids and particularly to *Wutingaspis* in the adult stage. The distinct transformation which takes place in *chinensis* on the cephalon from meraspid to holaspid are the postero-lateral migration of the anterior facial sutures and the inward migration of the posterior end of the palpebral lobe. As the result the lobe becomes semicircular as in the Olenellidae. In other words, the semicircular eyes are more developed than those of a quarter of a circle. This probably means that *Redlichia* s. str. is more developed or specialized than *Neoredlichia walcotti*, *Lusatiops* or *Wuting-aspis*. This conclusion is upheld by the fact that the *Neoredlichia walcotti* beds lie in Yunnan below the *Redlichia* beds. According to SAITO, *Neoredlichia nakamurai* occurs at the top of the *Redlichia* beds in North Korea. Therefore it can be said that *Neoredlichia* is more persistent than *Redlichia*.

Beside *Redlichia* there are some redlichioid genera in Eastern Asia. One of them is *Kueichouia* LU, 1942, which is said to be "closely allied to *Redlichia* and *Zacanthoides*, especially such species as *R. carinata*, *R. walcotti*, *R. inter-media* and *R. pustulosa* where the first and second belong to *Saukiandops*, and the third and fourth respectively to *Wutingaspis* and *Kuanyangia*. The nature of the last genus is, however, obscure, because its type-species is *R. pustulosa* LU which is represented by an imperfect cranidium. The type-species of *Kueichouia* is *K. liui* LU (Fig. 2b) which is represented by an cranidium orna-mented by numerous small pustules. It differs from *Redlichia* not only in the texture of the carapace but also by the relatively small palpebral lobe located posteriorly.

Redlichia, *Neoredlichia*, *Saukiandops*, *Wutingaspis* and *Redlichaspis* will be described later.

Redlichia (*Redlichops*) *blanckenhorni* R. and E. RICHTER, 1941, (Fig. 2g) is founded on imperfect cranidia and free cheeks from the Lower Cambrian of the Dead Sea area. It is the type species of *Redlichops* which is a distinct genus different from *Neoredlichia* in having a median tubercle on the neck ring, greater frontal limb, widely divergent anterior facial sutures which are starting from a point shortly distant from the glabella and much wider fixed cheeks in posterior. Its difference from *Redlichia* is greater.

Redlichina vologdini LERMONTOVA, 1940, (Fig. 2h) is the type-species of *Redlichina* LERMONTOVA, which was described from the Lower Cambrian of the Eastern and Western Sayans. Its glabella is very large, occipital spine stout, eye lobes comparatively small and preglabellar area expanded in *R. vologdini*. *Redlichina* may be said the Redlichiidae having a short conical convex glabella, 2 or 3 weak glabellar furrows, relatively small eyes and a long occipital spine. According to POKROVSKAYA (1960), this genus is repre-sented by many species in Tuwa.

Schagonaria tannuola POLETAYEVA, 1955, (Fig. 2f) from the Lower Cambrian of Tuwa which was placed by the author in the Paradoxidae, differs from *Paradoxides* in the glabellar furrows and some other aspects. The glabella and notably the palpebral lobes remind one of *Redlichina* alliance, but the eyes are far detached from the glabella at the posterior end.

The closest ally to *Schagonaria* may be *Olekmaspis* SUVOROVA, 1956, from the Lower Cambrian of the Siberian platform from which *Schagonaria* differs in the slow backward tapering of the glabella, the evanescence of the anterior glabellar furrows and some other biocharacters.

Micmaccopsis LERMONTOVA, 1940, was placed in the Protolenidae by the author, (1951), and in the Zacanthoididae by TCHERNYSHEVA, (1960). Its type species is *Micmaccopsis redlichoides* LERMONTOVA (Fig. 2a) which is as suggested by the tribal name, similar to *Redlichia* in the wide divergence of the anterior facial sutures and the lateral expansion of the preglabellar area beyond the parallels through the palpebral lobes. Like in *Schagonaria* and *Olekmaspis* the posterior end of the lobe is distant from the glabella.

Asthenaspis tenuis SUVOROVA, 1959, (Fig. 2d) from the Lower Cambrian of the Siberian platform is probably an aberrant genus of the Redlichiidae as opined by the author. The fixed cheeks are too narrow for the Protolenidae to which it bears also some alliance. The large preglabellar area crossed by the axial ridge and the bilobed pygidium with a broad axial lobe are the aspects as yet unknown in the Redlichiidae.
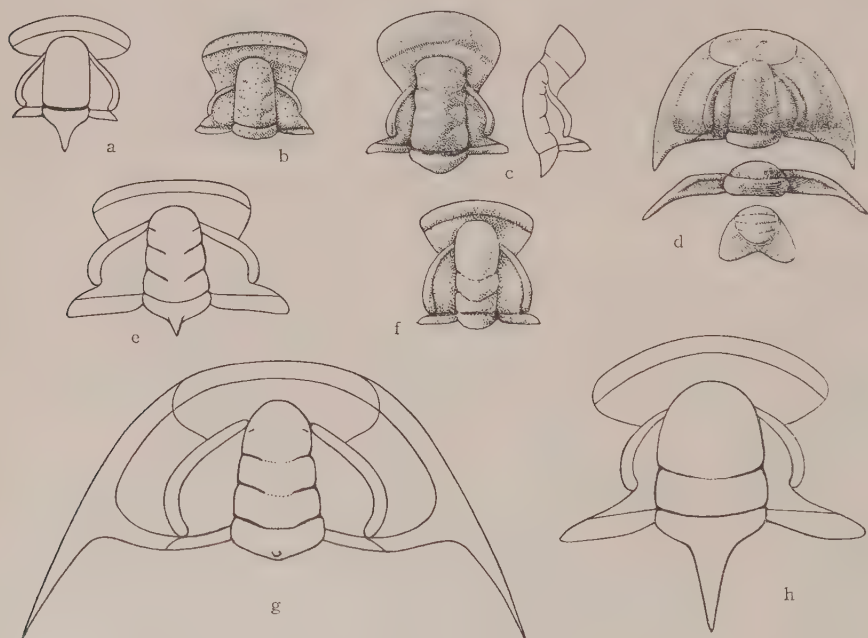

Figure 2.   Redlichiidae and allied genera.

a.   *Micmaccopsis redlichoides* LERMONTOVA
b.   *Kueichouia liui* LU
c.   *Lenaspis opipara* SUVOROVA
d.   *Asthenaspis tenuis* SUVOROVA
e.   *Wutingaspis tingi* KOBAYASHI
f.   *Schagonaria tannuola* POLETAYEVA
g.   *Redlichops blanckenhorni* RICHTERS
h.   *Redlichina vologdini* LERMONTOVA

Finally, *Lenaspis opipara* SUVOROVA (Fig. 2c) and *L. limbata* SUVOROVA, 1959, from the Lower Cambrian of the Siberian platform are, as the author noted, allied to the Dolichometopidae, but the anterior fixed cheeks are too large for the family.   The author referred *Lenaspis* to the Jakutidae, but the eye-lobes look more like those of the Redlichiidae.

It is still premature to reach the definite conclusion for these imperfectly known genera.   But there are gradations in the isolation of the palpebral lobe from the glabella on the posterior side.   The glabella is almost parallel sided in *R. cylindricus*, although none of *Redlichia* or *Neoredlichia* has the glabella tapering backward.

Genus *Redlichia* COSSMANN, 1902

1899.   *Hoeferia* REDLICH, non BITTNER, 1895, *Mem. Geol. Surv. India, N. Ser. 1*, p. 2.
1902.   *Redlichia* COSSMANN, *Rev. crit. Pal. 6 Ann.* p. 52.
1905.   *Redlichia* WALCOTT, *Proc. U. S. Nat. Mus. 29*, p. 24.
1912.   *Redlichia* MANSUY, *Mém. Serv. géol. l'Indochine 1*, p, 23.
1913.   *Redlichia* WALCOTT, *Research in China, Vol. 3*, p. 103.
1919.   *Redlichia* ETHERIDGE, *Trans. Proc. Roy. Soc. S. Australia, 43*, p. 386.
1934.   *Redlichia* SAITO, *Japan. Jour. Geol. Geogr. Vol. 11*, p. 219.
1935.   *Redlichia* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 118.
1937.   *Redlichia* RESSER and ENDO, *Manchurian Sci. Mus. Bull. 1*, p. 278.
1939.   *Mesodema* WHITEHOUSE, *Mem. Queensland Mus. Vol. 11, Pt. 3*, p. 187.
1944.   *Redlichia* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 19*, p. 99.
1950.   *Redlichia* LU, *Tichih Lunp'ing, Vol. 15*, p. 157.
1951.   *Redlichia* KOBAYASHI and KATO, *Jour. Fac. Sci. Univ. Tokyo, Sec. 2, Vol. 8, Pt. 3*, p. 104.
1952.   *Latiredlichia* HUPÉ, *Notes et Mèm. No. 103*, pp. 151, 194. (Type-species: *Redlichia* cfr. *walcotti* by SAITO).
1953.   *Redlichia* HUPÉ, *Ann. de Pal. Tom. 39*, p. 83.
1953.   *Latiredlichia* HUPÉ, *Ibid.* p. 86, (Type-species: *Latiredlichia saitoi* HUPÉ).
1953.   *Redlichia* CHANG, *Acta Pal. Sinica, Vol. 1*, p. 140.
1955.   *Redlichia* SCHINDEWOLF, *Neues Jahrb. Geol. Pal. Mh. 3*, S. 130.
1955.   *Redlichia* SCHINDEWOLF, *Akad. der. Wiss. und der Liter. Abh. der Math.-Naturw. Kl. Jahrg. 1955, Nr. 10*, S. 282.
1957.   *Redlichia* LU, *Index Fossils of China, Invertebrata, Vol. 3*, p. 261.
1958.   *Redlichia* ÖPIK, *Bureau of Min. Resources etc. Comm. of Australia, Bull. No. 42*, p. 9.
1959.   *Redlichia* POULSEN, *Treatise on Invert. Pal. Pt. 0–1*, p. 200.
1959.   *Latiredlichia* POULSEN, *Ibid.* p. 200.
1960.   *Redlichia* TCHERNYSHEVA, *Principles of Pal. 8*, p. 46.

Diagnosis:—Redlichiidae with facial sutures widely divergent from the junctions of palpebral lobes with frontal lobe of glabella and the palpebral lobes terminate near glabellar base.

Type-species:—*Hoeferia noetlingi* REDLICH, 1899.

Remarks:—There are more than 30 species which ought to be brought into taxonomic discussion of *Redlichia* as follows:

1.   *Olenellus* (?) *forresti* ETHERIDGE in FOORD, 1890.
2.   *Hoeferia noetlingi* REDLICH, 1899.
3.   *Hoeferia noetlingi* var. *angusta* REDLICH, 1899.

 4. *Hoeferia noetlingi* var. *lata* REDLICH, 1899.
 5. *Redlichia chinensis* WALCOTT, 1905.
 6. *Redlichia nobilis* WALCOTT, 1906.
 7. *Olenellus (Mesonacis) verneaui* MANSUY, 1907.
 8. *Redlichia walcotti* MANSUY, 1912.
 9. *Redlichia carinata* MANSUY, 1912.
10. *Redlichia* (?) *finalis* WALCOTT, 1913.
11. *Redlichia coreanica* SAITO, 1934.
12. *Redlichia nakamurai* SAITO, 1934.
13. *Redlichia longispinosa* KOBAYASHI, 1935.
14. *Redlichia manchuriensis* RESSER and ENDO in KOBAYASHI, 1935.
15. *Redlichia murakamii* RESSER and ENDO, in KOBAYASHI, 1935.
16. *Redlichia yunnanensis* RESSER and ENDO, in KOBAYASHI, 1935.
17. *Redlichia mansuyi* RESSER and ENDO, in KOBAYASHI, 1935.
18. *Redlichia kingi* MA, 1937.
19. *Redlichia angulata* SUN and CHANG, 1937.
20. *Redlichia foraminifera* SUN and CHANG, 1937.
21. *Redlichia fengyangensis* SUN and CHANG, 1937.
22. *Redlichia idonea* WHITEHOUSE, 1939.
23. *Mesodema venulosa* WHITEHOUSE, 1939.
24. *Redlichia intermedia* LU, 1940.
25. *Redlichia mai* LU, 1941.
26. *Redlichia pustulosa* LU, 1941.
27. *Redlichia saitoi* LU, 1950.
28. *Redlichia kobayashii* LU, 1950.
29. *Redlichia wangi* LU, 1950.
30. *Redlichia takooensis* LU, 1950.
31. *Redlichia meïtanensis* LU, 1950.
32. *Redlichia endoi* LU, 1950.
33. *Latiredlichia saitoi* HUPÉ, 1952.
34. *Archaeops lui* HUPÉ, 1952.
35. *Redlichia cylindrica* CHANG, 1955.
36. *Redlichia paucisegmenta* KOBAYASHI, 1961, (nov.)

Because I had no access to SUN and CHANG's paper, 1937, I leave their three species, *angulata*, *foraminifera* and *fengyangensis*, untouched. *Redlichia pustulosa* for which HUPÉ proposed *Kuanyangia* (1952) is represented by a fragmentary cranidium with pustulate test which is quite strange for the Redlichiidae. *Redlichia* (?) *finalis* is the type-species of *Redlichaspis*. *Redlichia walcotti*, *R. carinata*, *R. intermedia* (Fig. 3b) and *Archaeops lui* appear to belong to an identical or intimate species. They are distinguished subgenerically as *Saukiandops* from *R. nakamurai* which is the type-species of *Neoredlichia* SAITO, 1935. The remainder belongs to *Redlichia*.

Two groups may be distinguished in *Redlichia* with regard to the facial suture. One is the *chinensis* group having anterior facial sutures transversal

or nearly transversal and the other the *nobilis* group with diagnonal anterior sutures. The former comprises *chinensis*, *paucisegmenta*, *saitoi* and probably *wangi*. *Verneaui*, *kingi*, *manchuriensis*, *murakamii*, *yunnanensis* and *endoi* are considered synonyms of *chinensis*. R. *wangi* is similar to R. *chinensis*, but the palpebral lobe is more widely detached from the glabella at its rear end.

R. *mansuyi* is here taken for a synonym of R. *nobilis*. R. *kobayashii* is very close to it, but the glabella is extraordinarily large. R. *coreanica*, R. *cylindrica*, R. *mai* and R. *takooensis* are independent species of the *nobilis* group and R. *meitanensis* is probably conspecific with *takooensis*.

Finally, R. *forresti*, R. *neotlingi* and R. *idonea* are all members of the *nobilis* group of which a further mention will follow. According to ÖPIK " *Mesodema venulosa* is a *Redlichia* related to R. *idonea* and R. *forresti*," but "differs from R. *idonea* in having a venulose ornament, a deeper occipital furrow, a pointed edge of the occipital lobe and a more slender glabella."

Distribution:—Lower Cambrian in Southern and Eastern Asia. About ten species of *Redlichia* seem to occur in Australia among which R. *forresti*, R. *idonea* and R. *venulosa* are three described species. ÖPIK is of opinion that *Redlichia* in Australia is early Middle Cambrian except in South Australia. According to ÖPIK et al. (1956, 57) the *Redlichia* horizon lies in Northern territory below the *Xystridura* horizon in the some formation, but the faunal change between them looks to me sharp enough to draw the epoch boundary.

Redlichia forresti (ETHERIDGE in FOORD, 1890)

1890. *Olenellus* (?) *forresti* ETHERIDGE, jr. in FOORD, *Geol. Mag. N.S. Dec. 3, Vol. 7*, p. 99, pl. 4, figs. 2a–b.
1892. *Protolenus forresti* MATTEEW, *Canada Rec. Sci. 5*, p. 253.
1914. *Redlichia forresti* WALCOTT, *Smiths. Misc. Coll. Vol. 64, No. 1*, p. 62.
1919. *Redlichia forresti* ETHERIDGE, jr. *Trans. Roy. Soc. S. Australia, Vol. 43*, p. 387.
1919. aff. *Olenellus* (?) sp. or *Ptychoparia* sp. ETHERIDGE jr. *Ibid.* p. 382, pl. 39, fig. 1.
1958. *Redlichia forresti* ÖPIK, *Comm. of Australia, Bureau of Min. Resources, Geol. & Geophys. Bull. 42*, p. 5, pl. 1, figs. 1–2. pl. 2, figs. 1–4. pl. 3, figs. 1–4.

This is not only the first described one among the species now referred to *Redlichia*, but also one of the best known species. With a cranidium, a thoracic segment and an occipital (?) spine it was primarily described by ETHERIDGE as a species of *Olenellus* with query. WALCOTT was the first to take it for a member of *Redlichia*.

As noted by RICHTERS (1941), this species agrees well with R. *idonea* WHITEHOUSE from Queensland. However, it is said by WHITEHOUSE (1939) to differ from R. *idonea* "in being more inflated and with less well defined glabellar furrows." These distinctions may depend upon a matter of preservation, but they are undoubtedly two distinct species. According to ÖPIK (1958), " R. *idonea* has fifteen segments in the thorax, a dorsal spine on the eleventh segment and, in some specimens, a spine on the fourth segment as well," while " R. *forresti* has seventeen segments with spines on the twelfth and fourth."

This species has the cephalon similar to *R. nobilis*, but the post-cephalic shield is more slender and the thoracic segments are more numerous. A further distinction lies in that *R. nobilis* has only one axial spine on the eleventh segment.

Öpik distinguished two forms in *R. ferresti* with regard to the pygidium and interpreted them by sexial dimorphism. The common pygidium which is thought female is not essentially different from the pygidium of *R. chinensis*, *R. nobilis* or other Asiatic species. Judging from his restoration, the rare one which is thought male is quite different from all of the known pygidia of *Redlichia* in the outline, segmentation and the anterior pleurae. Because the restoration is made with a specimen on the weathered surface of a slab, it is desirable to be checked out with any better specimen of different kind of preservation.

Occurrence:—Northern Territory of Australia. As noted above, the age of this species is considered early Middle Cambrian by Öpik, but I think its Lower Cambrian age to be not the less probable.

Redlichia noetlingi (Redlich), 1899

1899. *Hoeferia noetlingi* Redlich, *Pal. Indica, N. S. Vol. 1*, p. 3, pl. 1, figs. 1–18a.
1910. *Redlichia noetlingi* Reed, *Pal. Indica, Ser. 15, Vol. 7, Mem. No. 1*, p. 7, pl. 1, fig. 14.
1941. *Redlichia noetlingi* King, *Rec. Geol. Surv. India, Vol. 75*, p. 3, pl. 1, figs. 1–3, pl. 3, figs. 1–9, pl. 4, figs. 1–10.
1955. *Redlichia noetlingi* Schindewolf, *Neues Jahrb. f. Geol. usw.* S. 130, Text-fig. 1–3.
1955. *Redlichia noetlingi* Schindewolf, in Schindewolf and Seilacher, *Abh. Math. Naturw. Kl. Akad. Wiss. Lit. Nr. 10*, S. 293, Taf. 6, Fig. 1–15, Taf. 7, Fig. 1–6, Text-fig. 1–5.

The cephalon restored by Redlich (1899) has the glabella more cylindrical than two cranidia which he called var. *angusta* and var. *lata*. Whitehouse (1939) selected var. *angusta* in fig. 1, pl. 1, in Redlich for the type of the species. Var. *lata* looks broader than var. *angusta*, but as discussed by King (1941), the difference of the outline depends upon distortion.

The facial suture was closely examined and the hypostoma discovered by Schindewolf (1955). In the presence of the depressed crescentic plate and the mode of attachment this hypostoma exactly agrees with that of *R. mansuyi* from Hupeh (1944) for which Lu (1950) erected *R. kobayashii*.

According to Walcott (1913), *R. nobilis* differs from this species " in the form of the posterior segment of the glabella and the somewhat less cylindrical form of the glabella." The distinction may be accepted if the comparison is made between this and the holotype of *nobilis* in fig. 12. But Walcott's *nobilis* in fig. 12b has the *noetlingi*-like glabella, although the palpebral lobe is larger.

This species is closely allied also to *R. forresti* and *R. idonea*. If the original illustration of *R. noetlingi* is compared with these Australian species, the glabella is evidently more cylindrical in *R. noetlingi*, but King's and

Schindewolf's illustrations of the species show that the difference is not so marked. King emphasizes the divergence of the anterior facial sutures for specific distinction, but the difference in ten degrees may not work for distorted specimens or even for specimens depressed by gravity compaction.

R. forresti, R. noetlingi, R. nobilis and R. idonea have the cephala so similar to one another that any substantial distinction is very difficult to point out. When complete carapaces are compared, however, forresti, nobilis and idonea can easily be distinguished. Unfortunately the existing knowledge of R. noetlingi is insufficient to answer for the questions, whether it can be identical with either one of the three allied species and at the same time what is its essential difference from them.

Until more is known, this species is accepted as the South Asiatic species of the nobilis group.

Occurrence:—Lower Cambrian; Salt Range and Spiti.

Redlichia chinensis Walcott, 1905

Plate XI, Figures 3–6; Text-figure 3a.

1905. *Redlichia chinensis* Walcott, *Proc. U.S. Nat. Mus. Vol. 29*, p. 25.

1907. *Olenellus (Mesonacis) verneaui* Mansuy, *Ann. des Mines, 10e Sér. Tom. 11*, p. 449, pl. 14, figs. 1–5.

1912. *Redlichia chinensis* Mansuy, *Mém. Serv. géol. l'Indochine, Vol. 1, Fasc. 2, Pt. 2*, p. 24.

1913. *Redlichia chinensis* Walcott, *Research in China, Vol. 3*, p. 104, pl. 7, figs. 11, 11a–d, pl. 24, figs. 1, 1a.

1930. *Redlichia chinensis* King, *Geol. Mag. 67*, p. 316, pl. 17, figs. 1–1c.

1931. *Redlichia kingi* Ma, *Tichih Lunp'ing, Vol. 2*, p. 158.

1934. *Redlichia chinensis* Saito, *Japan. Jour. Geol. Geogr. Vol. 11*, p. 220, pl. 26, figs. 1–10, text-fig. 1.

1935. *Redlichia chinensis* Kobayashi, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 120.

1935. *Redlichia manchuriensis* Resser and Endo in Kobayashi, *Ibid.* p. 120, pl. 21, figs. 6–7.

1935. *Redlichia murakamii* Resser and Endo, in Kobayashi, *Ibid.* p. 120, pl. 21, fig. 9.

1935. *Redlichia chinensis* Kobayashi, *Jour. Geogr. Tokyo, Vol. 47*, p. 363, pl. 4, fig. 3.

1937. *Redlichia manchuriensis* Resser and Endo, *Manchurian Sci. Mus. Bull. 1*, p. 238, pl. 18, figs. 11–24.

1937. *Redlichia murakamii* Resser and Endo, *Ibid.* p. 281, pl. 19, figs. 5–7.

1937. *Redlichia yunnanensis* Endo and Resser, *Ibid.* p. 383, pl. 19, fig. 4.

1941. *Redlichia chinensis* Lu, *Bull. Geol. Soc. China, Vol. 21*, p. 81, pl. 1, fig. 4.

1942. *Redlichia chinensis* Lu, *Ibid. Vol. 22, Nos. 3–4*, p. 182, pl. 1, fig. 4.

1944. *Redlichia verneaui* Kobayashi, *Japan. Jour. Geol. Geogr. Vol. 19*, p. 128, pl. 9, fig. 4, pl. 10, figs. 3–4.

1944. *Redlichia chinensis* Endo, *Bull. Central Nat. Mus. Manch., No. 7*, p. 60.

1950. *Redlichia endoi* Lu, *Tichih Lunp'ing, Vol. 15*, p. 166, fig. B4.

1951. *Redlichia chinensis* Kobayashi and Kato, *Jour. Fac. Sci. Univ. Tokyo, Sec. 2, Vol. 8, Pt. 3*, p. 99, pl. 1, figs. 1–15, pl. 2, figs. 1–13, pl. 3, figs. 1–9, pl. 4, figs. 1–12, pl. 5, figs. 1–6.

1953. *Redlichia chinensis* Chang, *Acta Pal. Sinica, Vol. 1*, p. 125, pl. 3, fig. 15, pl. 4, fig. 9.

1957. *Redlichia chinensis* LU, *Index Fossils of China, Invert. Vol. 3*, p. 261, pl. 137, figs. 12 13.

Description:—*Redlichia* with three transversal furrows on conical glabella beside an occipital furrow; anterior facial suture extending laterally for a long distance; thorax subelliptical and composed of 14 segments with an axial spine on the eleventh ring; posterior pleurae distinctly falcate; fifteenth segment semi-anchylosed; pygidium behind it roundly subquadrate with broad, somewhat bulbous axial lobe and a pair of tiny spines at postero-lateral angles.

Observation:—Irregular striae and a row of pits are clearly seen on the cranidia from a calcareous slate in the Mun'gyong area (Pl. XI, fig. 6), but they are not always well preserved. For the ventral morphology and ontogency of this species the reader is referred to the paper by KOBAYASHI and KATO (1951).

Comparison:—The lateral expansion of the cranidium in anterior is a
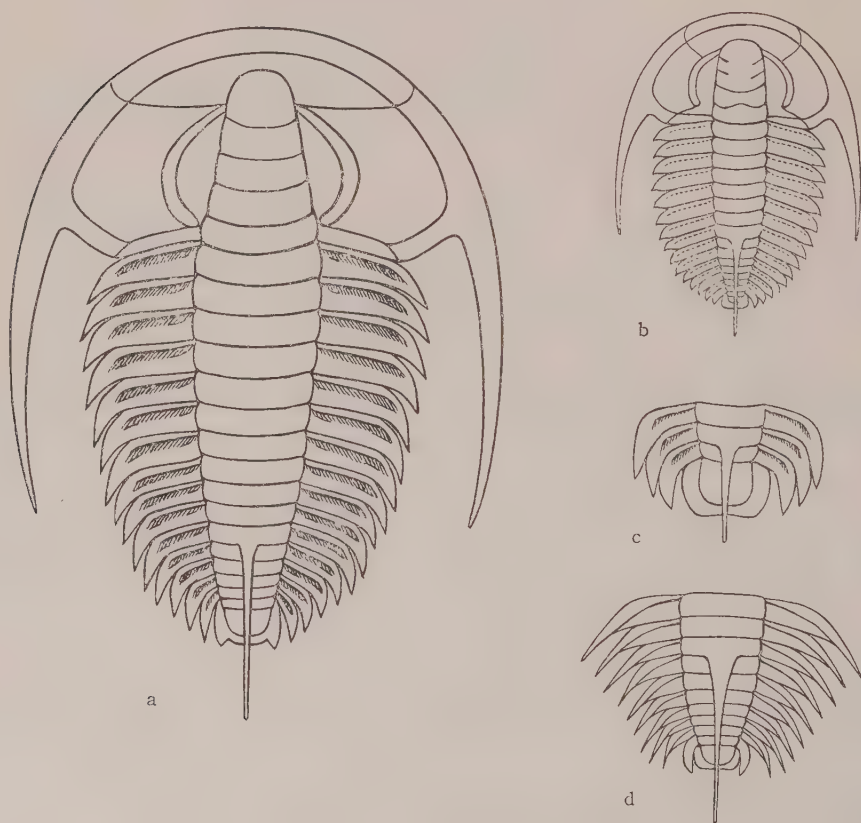

Figure 3.

a. *Redlichia chinensis* WALCOTT
b. *Neoredlichia (Saukiandops) intermedia* (LU)
c. *Redlichia paucisegmenta* KOBAYASHI, new species
d. *Redlichia longispina* KOBAYASHI

unique feature never seen in other species of *Redlichia*. I have suggested many years ago that *R. manchuriensis* and *R. murakamii* are closely related to *R. chinensis* (1935). It is now thoroughly proven that the first and second of them was named respectively for the early and late holaspid of the third species (ENDO, 1944, KOBAYASHI and KATO, 1951). As RESSER and ENDO (1937) mentioned themselves, " *R. yunnanensis* is intermediate in many respects between *R. murakamii* and *R. manchuriensis*." *R. yunnanensis* which they denominated for MANSUY's *R. chinensis* in fig. 1j, on pl. 12 was later found identical with *Olenellus* (*Mesonacis*) *verneaui* MANSUY, (KOBAYASHI, 1942).

KING's cranidium and free cheek of *R. chinensis* (1930) for which MA (1931) proposed *R. kingi* is inseparable from *R. chinensis* specifically, although another cranidium of KING's *chinensis* (1937) has the *nobilis* type of facial suture. LU's small cranidium of *R. endoi* having a short nuchal spine is probably a young holaspid of *R. chinensis*.

Occurrence:—Lower Cambrian in Korea, China, Indochina and Iran. In South Korea this species occurs in calcareous slate of Majo or Masong formation at a point about 1 km. southwest of Pongsaengdong (Hoshodo) on the north bank of the Yonggang (Eiko river). In North Korea it is found beside in situ, in the Kenjiho limestone conglomerate near Kyomipo (Kenjiho) as derived fossils. (KOBAYASHI, 1935). This species is reported to occur in North Australia by ÖPIK (1957, 58), but as yet neither described nor illustrated.

Redlichia nobilis WALCOTT, 1905

Plate IX, figures 1–8; plate X, figures 2–6; 8–11;
plate XIII, figure 19.

1905.   *Redlichia nobilis* WALCOTT, *Proc. U. S. Nat. Mus. Vol. 29*, p. 26.
1912.   *Redlichia chinensis* MANSUY (pars), *Mém. Serv. géol. l'Indochine, Vol. 1, Fasc. 2*, p. 24, pl. 2, figs. 1c–f.
1912.   *Redlichia nobilis* MANSUY, *Ibid.* p. 26, pl. 3, fig. 2.
1913.   *Redlichia nobilis* WALCOTT, *Research in China, Vol. 3*, p. 105, pl. 7, figs. 12–12e.
1934.   *Redlichia nobilis* SAITO, *Japan. Jour. Geol. Geogr. Vol. 11*, p. 223, pl. 26, fig. 18, text-fig. 2.
1935.   *Redlichia mansuyi* ENDO and RESSER in KOBAYASHI, *Jour. Fac. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 120.
1937.   *Redlichia mansuyi* ENDO and RESSER, *Manchurian Sci. Mus. Bull. 1*, p. 283, pl. 19, figs. 1–3.
1937.   *Redlichia chinensis* KING, *Pal. Indica, N. S. Vol. 22, No. 5*, p. 4, pl. 1, figs. 2A–C.
1944.   *Redlichia mansuyi* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 19*, p. 100, pl. 8, figs. 6–9.
1953.   *Redlichia nobilis* CHANG, *Acta Pal. Sinica, Vol. 1*. p. 126, pl. 3, fig. 13, pl. 4 figs. 1–4.

Description:—Cephalon about one-third as long as dorsal shield; posterior furrows transversal on glabella; palpebral lobe large semicircular; facial sutures extending diagonally from the anterior ends of the lobes and laterally from their posterior ends. Post-cephalic shield subovate or subtriangular; thorax composed of 14 segments with an axial spine on the eleventh ring;

axis of pygidium composed of 2 or 3 rings and a terminal lobe; anterior segment of pygidium semi-anchylosed.

Observation:—The Mun'gyong collection contains many nearly complete carapaces, although they are deformed. Three shields disposed in different directions are illustrated in fig. 8, on pl. IX for the study of secondary deformation. *All the relieves parallel to the trend of compression are as a rule weakened whereas those rectangular to the trend are strengthened.* The middle shield is compressed laterally. As the result the glabella takes a subcylindrical outline and lateral furrows become disconnected on the axis.

A cranidium in fig. 4, pl. X is an example laterally compressed. Another in fig. 3, pl. X is an example of sagittal compression. The glabellar and occipital furrows are all transversal in the latter while in the former the dorsal furrows are weakened at places, probably due to callosity of appendage-attachments. The palpebral lobe rises up and is fused with the frontal lobe of the glabella as seen in *Mesodema venulosa*. In still another cranidium in fig. 2, pl. X which is compressed diagonally, the palpebral lobe appears to be detached from the glabella for a long distance at the rear as in SAITO's *R. nobilis* (1934).

The genal spine is seen on a specimen in fig. 7, pl. IX to extend far behind the tenth thoracic segment.

In the Mun'gyong collection there are some hypostomata. In one of them (pl. X, fig. 5) a lateral and a posterior spine are preserved. Another specimen (pl. X, fig. 8) indicates its fusion with a posterior crescentic depressed plate in the same way as seen in the specimens from HUPÉ (1944). There is a row of pits along the marginal suture.

A long median spine exists on the axial ring of the 11th thoracic segment (pl. IX, fig. 3), but not always preserved. Caused by the attachment of legs, callosity sometimes comes out on each side of an axial ring (pl. IX, fig. 1). The distal end of the pleuron is subtriangular and sharply bent postero-laterally in anterior segments and bent back in posterior ones. These posterior pleurae are, however, not so much falcate as in *R. chinensis*.

The thorax appears to be composed of 15 segments, but the 15th segment is the semianchylosed one of the pygidium. The thorax combined with the pygidium forms a subtriangle, but its outline is more or less parabolic in *R. chinensis*.

There are some specimens which suggest that there are 2 segments between the 15th axial ring and the terminal lobe (pl. IX, fig. 2, pl. XIII, fig. 19). The 17th ring is, however, not always seen.

In the specimen in fig. 2, pl. IX the axial lobe is distinctly separated from the posterior rim by a groove. The lobe is twice as long as the rim. It is clearly recognized on the exfoliated part that the anterior segment is semi-anchylosed. Namely, the anterior axial ring is fused with the succeeding one, while the pleuron is separated from the main part of the pygidium. The pygidium behind the 15th segment is subquadrate. The pleural part is narrow and depressed. In this specimen the posterior margin is somewhat

sinuated mesially and provided with a very tiny spine on each side (pl. XIII, fig. 19).

The smallest specimen in the collection which is axially shortened, measures 6.1 mm. in length (pl. X, fig. 6). It has already the same number of thoracic segments as larger ones and the axial spine is present on the 11th thoracic segment. Nothing is known of the meraspid or earlier stage of this species.

Occurrence:—This species is widely distributed in Korea and China. In South Korea it is common in the Majo or Masong formation in Mun'gyong (Bunkei) district at the localities Kan 1, Ma 13, N1 and 7 and Am 271 and 274.

Redlichia coreanica SAITO, 1934

Plate XI, Figure 2.

1934. *Redlichia coreanica* SAITO, *Japan. Jour. Geol. Geogr. Vol. 11*, p. 223, pl. 26, figs. 11–14, text-fig. 3.
1952. *Redlichia coreanica* HUPÉ, *Notes et Mém. No. 103*, text-fig. 36–3.

Compared to *R. nobilis* the cranidium, especially the preglabellar area is narrower and the anterior facial sutures are more diagonal. On this account this species is similar to *Neoredlichia walcotti*, but different from that species in the suture starting at the junction of the palpebral lobe with the glabella and closer allocation of the posterior end of the lobe to the glabella.

Occurrence:—Lower Cambrian *Redlichia* shale of Chunghwa (Chuwa) area, North Korea.

Redlichia longispinosa KOBAYASHI, 1935

Text-figure 3d.

1935. *Redlichia longispinosa* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 121, pl. 21, figs. 3–5.

The cephalon is similar to *R. nobilis,* but the thoracic pleurae are projected postero-laterally into long nearly straight spines and the anterior axial rings of the thorax each bears a median tubercle.

In a paratype specimen there are six segments behind the 10th or 11th thoracic segment which bears a long axial spine. The seventh segment behind this spiniferous one is anterior semianchylosed segment of the pygidium.

Occurrence:—*Redlichia* shales at the foot of Yŏndubong (Mt. Entoho), east of Kojang (Kojo) and the southeastern slope of Wŏngong-ni (Genkokuri), both in Ch'osan (Sosan) area, North Korea.

Redlichia mai LU, 1941

1941. *Redlichia mai* LU, *Bull. Geol. Soc. China, Vol. 21*, p. 80, pl. 1, figs. 2a–b.
1950. *Redlichia mai* LU, *Tichih Lunp'ing, Vol. 15*, fig. B2.
1957. *Redlichia mai* LU, *Index Fossils of China, Invertebrata, Vol. 3*, p. 261, pl. 138, fig. 14.

"Facial suture first cutting the frontal brim inwards and backwards usually forming an angle of about 60° with the axis of glabella, etc. Thorax composed of fifteen segments.—Pygidium very small, grooved by a pair of discontinuous transverse furrows and distinctly separated." An axial spine is present on the 11th thoracic segment.

This species has the dorsal shield similar to *R. nobilis*, but differs in having long sharp and straight lateral spines on the thorax. Its close ally is *R. longispinosa* from which it can be distinguished by the smaller number of thoracic segments. The hypostoma of this species is quite unlike those of *R. chinensis* and *R. nobilis* in the rounded posterior outline without lateral projections.

Occurrence:—Lower Cambrian Tsanglangpu formation; Kumming, Yunnan, South China.

Redlichia takooensis Lu, 1950

1950. *Redlichia takooensis* Lu, *Tichih Lunp'ing Vol. 15*, p. 166, fig. C4.
1950. aff. *Redlichia meitanensis* Lu, *Ibid. Vol. 15*, p. 167, fig. B1.
1957. *Redlichia takooensis* Lu, *Index Fossils of China, Invertebrate, Vol. 3*, p. 261, pl. 139, fig. 1.
1957. aff. *Redlichia meitanensis* Lu, *Ibid. Vol. 3*, p. 261, pl. 138, fig. 16.

Similar to *noetlingi* and *nobilis* inclusive of *mansuyi*, but having an occipital spine on the cephalon, 15 thoracic segments, an axial spine on the 10th, instead of the 11th in *mansuyi* or *nobilis*, and the 16th segment semi-anchylosed and lying in the pygidium. *Meitanensis* is represented by the cranidium very close to *takooensis*.

Occurrence:—Lower Cambrian; Kueichou.

Redlichia saitoi Lu, 1950

Plate X, Figure 7.

1960. *Redlichia saitoi* KOBAYASHI, *Jour. Fac. Sci. Univ. Tokyo. Sec. 2, Vol. 12, Pt. 2*, p. 343. (See for synonymic reference.)

Occurrence:—Dark grey shale of the Beiho or Myobong slate formation at Dai 1, South Korea; upper *Redlichia* shale in Chunghwa (Chuwa) area, North Korea; archaeocyathid limestone in Hupeh, Central China.

Redlichia cfr. *cylindrica* CHANG, 1953

Plate X, figure 1.

1953. cfr. *Redlichia cylindrica* CHANG, *Acta Pal. Sinica, Vol. 1*, p. 141, pl. 4, figs. 5–7.

The species is characterized by anterior sutures of *nobilis* type, parallel-sided glabella and a tiny median spine on the neck. A cranidium at hand reveals the close alliance to this species, although the median spine is indiscernible on the occipital ring.

Occurrence:—Calcareous shale of Majo or Masong formation at Ma 26. This species was originally described from the Lower Cambrian Shihpai shale in Hupeh by CHANG.

Redlichia paucisegmenta KOBAYASHI, new species

Text-figure 3c.

1935. *Redlichia* sp. KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2,* p. 119, pl. 21, fig. 8.

A postcephalic shield, 14 mm. long, is quite similar to *R. chinensis*, but there is only one segment between the spiniferous 11th and the pygidium proper, and the 12th segment is possibly semi-anchylosed. Thus it looks like an early holaspid of *chinensis* about 6 mm. long or about 3.3 mm. in postcephalic length, but quite different from *chinensis* of the same stage of growth.

Occurrence:—*Redlichia* shale at Masan-ni (Masanri) near Kyomipo (Kenjiho), North Korea.

Genus *Neoredlichia* SAITO, 1936

1936. *Neoredlichia* SAITO, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 3,* p. 363.
1952. *Neoredlichia* HUPÉ, *Notes et Mém. No. 103,* pp. 149, 167.
1953. *Neoredlichia* HUPÉ, *Ann. de Pal. Tom. 39,* p. 83.
1959. *Neoredlichia* POULSEN, *Treatise on Invert. Pal. 0-1,* p. 200.
1960. *Neoredlichia* TCHERNYSHEVA, *Principles of Pal. 8,* p. 65.

Diagnosis:—Redlichiidae with anterior facial sutures issuing from points fairly apart from glabella and being only slightly divergent; palpebral lobe detached from glabella for a short distance at the rear end.

Type-species:—*Redlichia nakamurai* SAITO, 1935, Plate XI, figure 1.

Remarks:—In SAITO's type cranidia the facial sutures are not so subparallel as indicated in his retouched illustration, although not so widely divergent as in *Wutingaspis*.

Neoredlichia latigea HUPÉ from the zone of *Daguinaspis* and *Resserops* has the cranidium closely resembling that of *N. nakamurai*, although the former differs from the latter in the palpebral band running forward along the frontal lobe of the glabella. A further confirmation of their congenity is needed with other parts of the carapace.

Distribution:—Lower Cambrian; Eastern Asia and (?) Morocco.

Subgenus *Saukiandops* HUPÉ, 1952

1952. (?) *Pararedlichia* HUPÉ, *Notes et Mém. No. 103,* pp. 149, 164. (Type-species: *Pararedlichia pulchella* HUPÉ, 1952.)
1952. *Archaeops* HUPÉ, *Ibid. No. 103,* pp. 152, 194. (Type-species: *Archaeops lui* HUPÉ, 1952, i. e. *Redlichia walcotti* by LU, 1941).
1953. *Saukiandops* HUPÉ, *Ann. de Pal. Tom. 39,* p. 86.
1953. *Archaeops* HUPÉ, *Ibid. Tom. 39,* p. 86.

1959.   (?) *Pararedlichia* POULSEN, *Treatise on Invert. Pal. Pt. 0–1*, p. 200.
1959.   *Saukiandops* POULSEN, *Ibid. 0–1*, p. 200.
1959.   *Archaeops* POULSEN, *Ibid. 0–1*, p. 200.

Type-species :—Redlichia walcotti MANSUY, 1912.

No more than subgeneric separation is possible for *Saukiandops* from *Neoredlichia*, because it differs from *Neoredlichia* simply in the diagonal anterior suture.

The two MANSUY's species are based on detached cranidia which are deformed in different degrees, but they agree in the anterior facial sutures which start from the eye-band at a short distance from the glabella and extended diagonally. It is possible that LU's *walcotti* or *carinata* is respectively an axially or a laterally compressed form of the same species.

Redlichia intermedia LU, 1940, (Fig. 3b) belongs undoubtedly to the same specific group. Merit to LU the ontogeny of this species is well clarified. The early meraspids (1.63–1.93 mm. long) have long spines in the anterior segments. Later (2.295 mm. long) these spines loose their significance and an axial spine appears on the ninth thoracic segment, instead of the eleventh in *Redlichia chinensis* and *R. nobilis*. On the dorsal shield, 22 mm. long, there are at least 17 axial rings behind the cephalon, but it is a question whether the 17th is the last axial ring or whether it belongs to the pygidium.

Insofar as the cranidia are concerned, three species of *Pararedlichia* (*subtransversa*, *pulchella* and *rochi*) which HUPÉ described from the zone of *Fallotiopsis tazemmourtensis* look very similar to *S. walcotti*, although their congenity must be proved with other parts of the carapace.

*Distribution :—*Lower Cambrian ; Eastern Asia and (?) Morocco.

Genus *Redlichaspis* KOBAYASHI, 1935

1935.   *Redlichaspis* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 121.
1952.   *Redlichaspis* HUPÉ, *Notes et Mém. No. 103*, p. 149.
1953.   *Redlichaspis* HUPÉ, *Ann. de Pal. Tom. 39*, p. 83.
1959.   *Redlichaspis* POULSEN, *Treatise on Invert. Pal. 0–1*, p. 200.
1960.   *Redlichaspis* TCHERNYSHEVA, *Principles of Pal. 8*, p. 64.

Type-species :—Redlichia ? finalis WALCOTT, 1905.

*Remarks :—*It is a remarkable fact that the subquadrate glabella, long nuchal spine and subparallel anterior facial sutures show the good agreement of this genus with *Sunia*, but the presence of the frontal limb longer than the frontal rim and the three pairs of profound oblique lateral furrows on the glabella preclude its reference to the Dolichometopidae.

Distribution :—Redlichia finalis was referred to Middle Cambrian by WALCOTT, but it is considered Lower Cambrian by POULSEN, 1959. It is said to occur in association with *Ptychoparia* (?) sp. (pygidium) in green shale near the middle of the Changhia limestone at loc. C_{58} near Kao-kia-pu, Shantung below the horizon of loc. C_{57}, containing *Amphoton deois, Dorypyge richthofeni* and others in the lower series of the Kiulung group. Therefore the *finalis*

horizon is not younger than the Tangshihan. The association of a ptychpariid suggests its possibility of being Shihchiaoan, but because the fossils were contained in green shale, they are likely early Tangshihan or early Middle Cambrian rather than Shihchiaoan or late Lower Cambrian.

Family Dolerolenidae KOBAYASHI, 1951

Similar to the Redlichiidae, but palpebral lobes are shorter and remote from from glabella at the posterior ends. Postero-lateral limb of fixed cheek moderate in size.

Beside *Dolerolenus* LEANZA, 1949 (i. e. *Olenopsis* BORNEMANN, 1891, non AMEGHINO, 1889), this family includes *Wutingaspis* KOBAYASHI, 1944 and probably *Abadiella* HUPÉ, 1953.

Genus *Wutingaspis* KOBAYASHI, 1944

1944.   *Wutingaspis* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 19*, p. 130.
1953.   *Wutingaspis* CHANG, *Acta Pal. Sinica, Vol. 1, No. 3*, p. 141.
1959.   *Wutingaspis* HENNINGSMOEN, *Treatise on Pal. 0–1*, p. 205.

Type-species:—*Wutingaspis tingi* KOBAYASHI, 1944. (Fig. 2e)
This genus appears most intimate to *Neoredlichia* (*Saukiandops*), but its independence becomes evident by the comparison of the holotype of *tingi* with the type cranidium of *Redlichia intermedia* LU, 1940, pl. 10, fig. 7. They are about the same stage of growth, but are quite different from each other. The former is considerably broader than the latter. The fixed cheek is broader than the glabella in the former whereas the reverse proportion is the case of the latter. In the palpebral lobe terminating back at a remote point from the glabella and the fixed cheek having the postero-lateral limb of moderate size this genus is somewhat deviated from the redlichiid to the protolenid and ellipsocephalid. These characteristics are clearly seen also in *Wutingaspis conditus* KOBAYASHI.

It is quite certain that *Wutingaspis intermedia* from western Hupeh belongs to *W. tingi* because the cranidium in CHANG, 1953, pl. 3, fig. 3 is almost identical with the holotype of *tingi*. As pointed by CHANG, *Yunnanocephalus yaoyingensis* may be a synonym of *tingi*, seeing that the cranidium of the former is closely allied to CHANG's in fig. 7.

Distribution:—Lower Cambrian of East Asia.

Family Yinitidae HUPÉ, 1953

Genus *Yinites* LU, 1945

1945.   *Yinites* LU, *Bull. Geol. Soc. China, Vol. 25*, p. 188.
1953.   *Yinites* HUPÉ, *Ann. de Pal. Tom. 39*, p. 86.
1957.   *Yinites* LU, *Index Fossils of China, Invert. vol. 3*, p. 262.
1959.   *Yinites* HARRINGTON, *Treatise on Invert. Pal. 0–1*, p. 205.

Type-species :—*Yinnites typicalis* LU, 1945. (Text-fig. 4)

The type-species was founded on cranidia and pygidia from the early Middle Cambrian Chintingshan formation at Meitan, Northern Kueichou. It was placed in the Zacanthoididae, but "regarded as a form derived from a line of Redlichiidae". The pygidium, however, has a pair of long spines like those of *Albertella* and the Crepicephalidae. Then, HUPÉ (1952) pointed out that the genus probably belongs to the *Redlichioidae du 1er groupe*. Subsequently he proposed a new family to include *Yinites* and *Labradoria* RESSER, 1936, from the Lower Cambrian of North America and referred it to the superfamily with query.
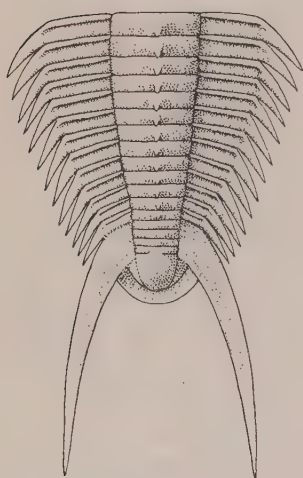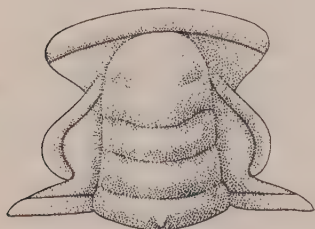
Labradoria is, however, different from *Yinites* in the development of glabellar furrows, course of eye-band and subparallel facial sutures. HARRINGTON (1959) properly excluded *Labradoria* from the Yinitidae and placed it in the Ellipsocephalacea.

Prior to this LU (1957) illustrated a specimen composed of 13 thoracic segments and a pygidium. The axial ring of the thorax bears a pointed median tubercle. On the cranidium illustrated on this occasion two posterior furrows are transversal and the glabella and cranidium are broader, while on the type cranidium only a posterior furrow runs across the narrower glabella on the narrower cranidium. Therefore these difference may be secondary products.

Figure 4. *Yinites typicalis* LU.

Family Ellipsocephalidae MATTHEW, 1887

On the previous occasion (1935) I have classified this family into the Ellipsocephalinae, Agraulinae and the Kingstoninae and tentatively referred 10 genera to the first subfamily. RESSER (1942) eliminated Croixian *Ellipsocephaloides* out of the subfamily, suggesting its isolation in the family rank, but giving no statement as to its taxonomic position. Lately HUPÉ (1953) placed his Ellipsocephaloidae in the Telephoidae. The cranidium of the genus bears some aspects allied to the Komaspidae, especially to *Chariocephalus*. Its spiny pygidium is, however, nothing like a telephoid's, but it resembles certain Remopleuracea, *Protapatokephalus* for example. It is unclassified in Treatise (1950). *Protagraulos* MATTHEW is another ambiguous genus, but it is probably either an agraulid or an ellipsocephalid.

The other genera of the Ellipsocephalinae were *Ellipsocephalus*, *Kingaspis*,

Protolenus, Bergeronia, Micmacca, Mohicana, Blayacina and *Palaeolenus* to which *Bigotina, Ferralsia* and Sinolenus were later (1944) added. At present most taxonomists agree to group them in the Ellipsocephalacea which include the Ellipsocephalidae and Protolenidae beside the Palaeolenidae and some others which suit for an author or another.

The family, Protolenidae, was proposed by R. and E. RICHTER to include *Bigotina, Lusatiops, Ferralsia* and *Aldonaia*, beside *Protolenus*. The authors emphasized the divergent anterior sutures for its prime distinction from the Ellipsocephalidae, but they are commonly subparallel among protolenids. It is known further that the sutures change from diagonal to parallel through growth of *Palaeolenus* and other protolenids. HENNINGSMOEN (1951) suggested the probable synonymy of the Protolenidae with the Ellipsocephalidae, but in Treatise he accepted the two as two major branches of the Ellipsocephalacea which superfamily is in turn approximate the Ellipsocephalinae in 1935.

The ellipsocephalids have been generally included in the Ptychopariida. WHITEHOUSE (1939) erected the Ellipsocephalida as a distinct Lower Cambrian stock. In the same year SCHWARZBACH discovered an archeapygidium associated with *Protolenus lusaticus* and claimed that *Protolenus* constitutes a group with *Paradoxides, Olenopsis* (i. e. *Dolerolenus*), *Redlichia* and the Mesonacidae (i. e. Olenellidae), because the pygidium is ptychoparioid in *Ellipsocephalus*. *P. lusaticus* is, however, sufficiently distinct from *Protolenus* s. str. to be the type-species of *Lusatiops*.

The anaprotaspids of *Palaeolenus* and *Dolerolenus* are almost identical and *Redlichia* passes the protolenid stage. The protolenids are however, different from the redlichiids in the migration of the sutures that they shift toward the axis, but never become transversal as in *Redlichia chinensis*.

HUPÉ (1952, 53) divided the Redlichioidae into two groups, namely one with the subconical glabella and the other with the glabella subquadrate or delating forward. In his classification the Protolenidae and Ellipsocephalidae were respectively placed in the first and second group. These two families are, however, so intimate that many authors disagree with this separation. The broad fixed cheeks, subrectangular palpebral lobe and eye-ridge and the anterior facial sutures distant from the glabella are three fundamental distinctions of these families from the Redlichiidae. They are again combined in the Ellipsocephalidea in Treatise.

The Redlichiidae and Protolenidae are not so widely apart from each other as previously considered, if the dolerolenids are placed between them, but either one of the two families is ancestral to the other. In my opinion the Ellipsocephalidae (i. e. Ellipsocephalacea in Treatise) comprise more than three subfamilies, though their morphic boundaries are arbitary.

1. Ellipsocephalidae with subconical glabella . . . . Protoleninae.
1'. Similar to Protoleninae but with parafrontal band or double palpebral-ocular ridge . . . . Termierellinae.
2. Ellipsocephalidae with subcylindrical or forwardly dilating glabella . . . . Palaeoleninae.

2′. Similar to Palaeoleninae but with considerably broad cranidium and fixed cheek ....Aldonaiinae

3. Ellipsocephalidae resembling protolenids but with ptychoparioid-pygidium ....Ellipsocephalinae.

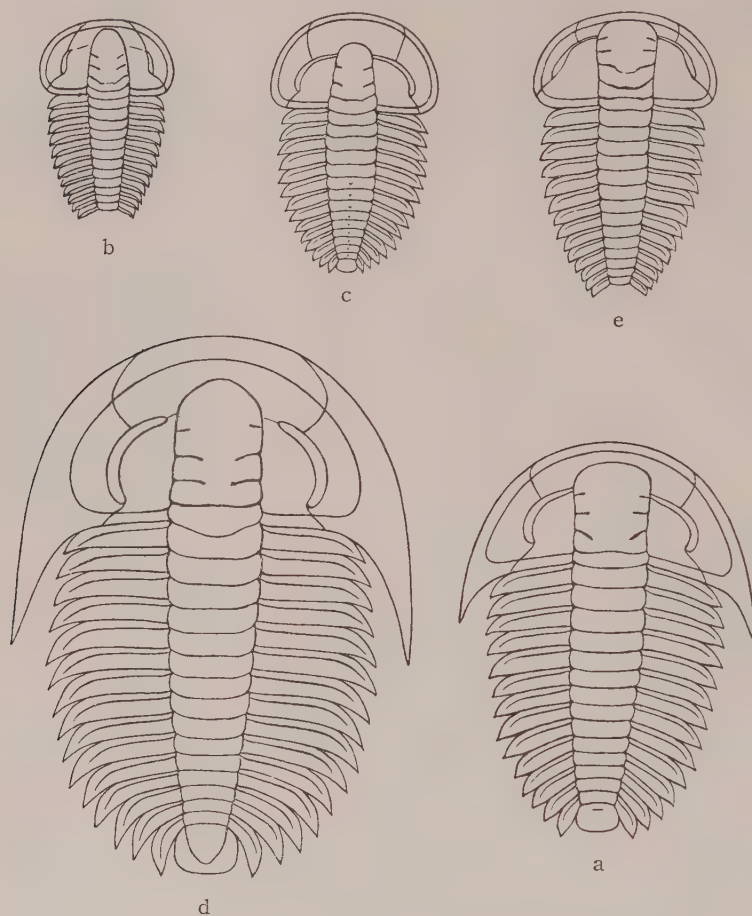Whether the Ellipsocephalinae are so widely apart from agraulids as in the order rank is really a question.

Figure 5. Ellipsocephalidae and allied genera.

    a. *Palaeolenus deprati* MANSUY
    b. *Sinolenus trapezoidalis* KOBAYASHI
    c. *Yunnanocephalus yunnanensis* (MANSUY)
    d. *Bergeroniellus asiaticus* LERMONTOVA
    e. *Cheiruroides primigenius* (SAITO)

Subfamily Protoleninae R. and E. RICHTER, 1948

This subfamily is represented in Southern and Eastern Asia by a few isolated occurrences in Israel, Iran, China and Korea. KING's *Anomocare megalurus* (1930) from the Lower Cambrian of Iran is most probably a proto-

lenid with a finely granulate test. *Protolenus hupeiensis* CHANG (1953) appears a protolenid, but it differs from *Protolenus* primarily in the lack of the frontal limb. Neither *Protolenus orientalis* of Israel nor *P. orientalis* of North Korea belongs to *Protolenus* s. str., but to *Coreolenus* which is here considered a subgenus of *Lusatiops*.

Lusatiops is widely spread from Europe to Australia through the Mediterranean region. The Proteleninae may be the best location for *Pararaia* which occurs in South Australia. *Kaydella* POKROVSKAYA (1959) and *Elegestina* POKROVSKAYA from Tuwa, both having conical glabellae are North Asiatic representatives of this subfamily.

Bergeroniellus LERMONTOVA, 1940, (Fig. 5d) *Paramicmacca* LERM. 1951, (Fig. 6d) *Bergeroniopsis* LERM. 1951, *Olekmaspis* SUVOROVA, 1956, and *Lermontovia* SUVOROVA, 1956, which generally have subcylindrical glabellae, more or less tapering back and occasionally angulated in front, are not typical protelenids, but may be better placed in the Palaeolenidae. *Anabaraspis* LERM. 1951, (Fig. 6c) *Schistocephalus* LERM. (TCHERNYSHEVA), 1956 (Fig. 6i) have also similar glabellae, but one or three glabellar furrows are transversal in them. TCHERNYSHEVA may be correct to locate them in the Paradoxidae.

Finally, *Sinolenus* KOBAYASHI, 1944, (Fig. 5b) and *Yunnanocephalus* KOBAYASHI, 1936 (Fig. 5c) (i.e. *Pseudoptychoparia* TING, 1940) are two aberrant genera probably of this subfamily.

Genus *Lusatiops* R. and E. RICHTER, 1941

1941. *Lusatiops* R. & E. RICHTER, *Abh. Senckenberg. Naturf. Gesell. 455*, S. 43.
1952. *Lusatiops* HUPÉ, *Notes et Mém. No. 103*, pp. 156, 216.
1953. *Lusatiops* HUPÉ, *Ann. de Pal. Tom. 53*, p. 150.
1959. *Lusatiops* HENNINGSMOEN, *Treatise of Pal. 0-1*, p. 212.
1960. *Lusatiops* TCHERNYSHEVA, *Principles of Pal. 8*. p. 68.

Type-species:—Protolenus lusaticus SCHWARZBACH, 1933.

In Eastern Asia the genus is represented by *Lusatiops sinensis* CHANG, 1953, from the Lower Cambrian of Western Hupeh which shows the divergence of the anterior sutures. As the author suggested later a new generic name, *Hsuaspis*, for it, it differs from *lusaticus* in the robust glabella of the cylindroconical outline, very thick eye-ridge and eye-lobe and strongly arcuate frontal border.

Paratermierella HUPÉ, 1952, founded on *P. elegans* HUPÉ from Morocco is, as TCHERNYSHEVA synonymized with this genus, a close ally which simply differs from *Lusatiops* in the elongation of the glabella as far as the frontal border.

Distribution:—Lower Cambrian; Germany, Spain, (?) Morocco and Central China. The genus is reported to occur in Australia (ÖPIK et al. 1957).
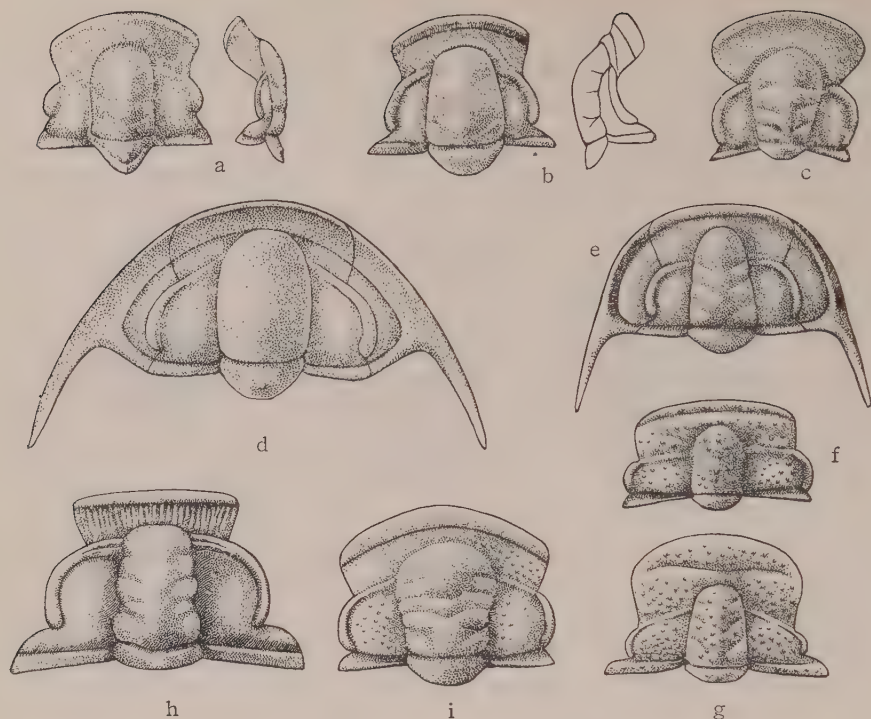
Figure 6. Ellipsocephalidae and allied Genera.

a. *Hupeia pulchra* KOBAYASHI
b. *Elganellus probus* SUVOROVA
c. *Anabaraspis splendens* LERMONTOVA
d. *Paramicmacca sibirica* LERMONTOVA
e. *Lusatiops (Coreolenus) coreanicus* (SAITO)
f. *Aldonaia ornata* LERMONTOVA
g. *Volonellus granulatus* IVSHIN
h. *Budaiaspis vologdini* LERMONTOVA
i. *Schistocephalus juvenia* TCHERNYSHEVA

Subgenus *Coreolenus* HUPÉ, 1952

Lusatiops (Coreolenus) coreanicus (SAITO), 1933

Text-figure 6e.

1933. *Protolenus coreanicus* SAITO, *Japan. Jour. Geol. Geogr. Vol. 10*, p. 148, text-figs. 1–52.
1934. *Protolenus coreanicus* SAITO, *Ibid. Vol. 11*, p. 226, pl. 27, figs. 21–24.
1952. *Coreolenus coreanicus* HUPÉ, *Notes et Mém. No. 103*, p. 215, text-fig. 48a.

This species attracted attention of Cambrian students by the fact on the occurrence that the so-called *Protolenus* bed lies below the *Redlichia* beds in North Korea. As GRABAU pointed out already in 1937, this species bears many distinctive features from *Protolenus* MATTHEW, among which the slender

conical glabella is most remarkable.

RICHTERS referred the Korean species to his *Lusatiops*, while HUPÉ erected *Coreolenus* for it.   As *Coreolenus* was subsequently synonymized by HEN-NINGSMOEN (1959) with *Lusatiops*, they have many common characters, but nevertheless the difference of the facial sutures requires their separation at least in the subgeneric rank.   Namely, *Protolenus lusaticus* SCHWARZBACH, 1933, is the type-species of *Lusatiops* which has the anterior sutures widely divergent, but they are subparallel or only a little divergent in *Coreolenus coreanicus*.

Another species of *Coreolenus* is probably *Protolenus orientalis* PICARD, 1942, from the Dead Sea, having a greater palpebral lobe.   The anterior sutures appear remarkably parallel in this species.

Distribution:—Lower Cambrian; Korea and Israel.

Subfamily Termierellinae HUPÉ, 1953

This subfamily as defined above includes the Myopsoleninae.   Because it has been indigenous to the western Mediterranean region in the early Cambrian epoch, the discovery of *Budaiaspis* LERMONOTOVA (REPINA), 1956 and *Elganellus* SUVOROVA, 1958, in the Lower Cambrian of Siberia is of special interest.

SUVOROVA has instituted *Elganellus* in the Neoredlichiidae, in describing *probus, pensus, acceptus* and *elegans* where the first is the type-species (Fig. 6b).   Except for the bifurcate posterior glabellar furrow, it looks an ellipsocephalid as considered by TCHERNYSHEVA (1960).   The distinct parafrontal band is strongly suggestive of its alliance to this subfamily.

Budaiaspis founded on *B. vologdini* LERM. (Fig. 6h) was placed in the Redlichiidae by the author and in the Neoredlichiidae by TCHERNYSHEVA (1960).   As noted by LERMONTOVA it resembles *Metadoxides* in the outline of the cranidium and relatively short palpebral lobe, but in *Metadoxides* the glabella is longer and lateral furrows are united on the axis of the glabella. In the relative size of the glabella and palpebral lobe and the general aspect of the cranidium it is not the less similar to *Yunnanocephalus*, but the glabella of that genus has only two pairs of lateral furrows.   The radial preglabellar striae and the pygidium which is broad and semicircular and the pleural lobes flat and nearly as wide as the axial lobe are suggestive of ptychopariid alliance.

It is provisional to locate this genus here because of the double eye-ridge and presence of the frontal band which do not occur in *Yunnanocephalus*, *Metadoxides* and ptychopariid genera.

Subfamily Palaeoleninae HUPÉ, 1952

HUPÉ (1952, 53) classified his Palaeolenidae into the Palaeoleninae, Kingaspinae and the Hartshillinae.   The last comprising *Hartshillia* and *Hartshillina*, however, belongs to the Conocoryphidae as considered by many authors

(Poulsen, 1959, Tchernysheva, 1960). Here the two others are brought together. Hupé included in his Palaeoleninae the following 5 Asiatic genera:

Palaeolenus Mansuy, 1912 (*Palaeolenus douvillei* Mansuy) (Fig. 5a)
Cheiruroides Kobayashi, 1935 (*Arthricocephalus ? primigenius* Saito) (Fig. 5e)
Luaspis Hupé, 1953 (*Pseudoptychoparia reedi* Lu)
Hoffetella Hupé, 1953 (*Micmacca elongata* Lu, 1941)
Hupeia Kobayashi, 1944 (*Hupeia pulchra* Kobayashi, 1944) (Fig. 6a)

In describing a new species from the Lower Cambrian of Tuwa, Pokrovskaya (1959) placed *Cheiruroides* properly in the Oryctocephalidae. This reference agrees with what Rasetti has done in the same year in Treatise.

Much cannot be mentioned of *Luaspis* and *Hoffetella* because they are represented by poor specimens. *Micmacca transversa* and *M. elongata* of which the latter is the type-species of *Hoffetella*, are an axially and a laterally compressed form respectively, but possibly they belong to an identical species. Beside *Palaeolenus* and *Hupeia*, there is a very distinct genus called *Ichangia* by Chang, 1957. Its type-species is *Ichangia ichangensis* Chang, 1957, from the Lower Cambrian of Hupeh which was, however, simply illustrated.

Incidentally, Henningsmoen (1959) has referred *Manchurocephalus* Endo, 1944, to this subfamily, but its type-species is not *Palaeolenus deprati* Mansuy, 1912, as cited by him in Treatise, but *Coosia deprati*, 1915. Because the last species is congeneric with *Coosia asiatica* Kobayashi, 1936, which is in turn the type-species of *Paracoosia* Kobayashi, 1936, *Manchurocephalus* is, as pointed out already (1951), a synonym of *Paracoosia*.

Genus *Palaeolenus* Mansuy, 1912

1912. *Palaeolenus* Mansuy, Mém. du Serv. géol. de l'Indochine, vol. 1, Fasc. 2, p. 27.
1935. *Palaeolenus* Kobayashi, Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2, p. 197.
1935. *Ferralsia* Cobbold, Ann. Mag. Nat. Hist. Ser. 10, Vol. 16, p. 31.
1941. *Palaeolenus* Lu, Bull. Geol. Soc. China, Vol. 21, p. 82.
1944. *Palaeolenus* Kobayashi, Japan. Jour. Geol. Geogr. Vol. 19, p. 129.
1952. *Ferralsia* Hupé, Notes et Mém. No. 103, p. 157.
1952. *Palaeolenus* Hupé, Ibid., p. 158.
1953. *Ferralsia* Hupé, Ann. de Pal. Tom. 39, p. 96.
1959. *Palaeolenus* Henningsmoen, Treatise on Invert. Pal. Pt. O–1, p. 209.
1959. *Ferralsia* Henningsmoen, Ibid. p. 211.
1960. *Palaeolenus* Tchernysheva, Principles of Pal. 8, p. 66.

Diagnosis:—Similar to protolenids, but with subquadrate glabella, sometimes contracted at the mid-length or more or less expanding forward, narrow, slightly convex frontal limb, genal spine on narrow free cheek, about 14 segments in thorax and small rounded pygidium with a broad axis.

Type-species:—*Palaeolenus douvillei* Mansuy, 1912, (Fig. 5a).

Remarks:—Mansuy compared this genus with *Olenoides* (*Neolenus*), *Zacanthoides*, *Redlichia* and some other genera, but neither *Protolenus* nor *Ellipsocephalus* to which it is undoubtedly related, as pointed out already

(1935).

COBBOLD compared his *Ferralsia* with *Ellipsocephalus*, *Micmacca*, *Protolenus* and *Strenuella*, but overlooked *Palaeolenus*. As noted by LU (1941, 50), the similarilty of *Ferralsia* with *Palaeolenus* is striking.   They have the same kind of glabella, palpebral lobe, hypostoma, facial suture and so forth.   The thoracic segments number about 14 in the two genera.   There appears to exist no distinction of generic value between them.

Beside the type-species this genus includes *P. deprati* MANSUY, *P. lantenoisi* MANSUY, *P. tingi* LU, *Ferralsia blayaci* COBBOLD and probably *Protolenus pustulatus* COBBOLD where the penultimate species is the type of *Ferralsia*.   Here a new species, *Palaeolenus aotii*, is added to them.

In *Palaeolenus* the cephalon is semicircular and a little broader than the thorax.   The glabella may be more or less expanded forward or contracted at the middle.   Nevertheless, it is always long and subquadrate.   It occurs to be subrounded or subtrigonally projected in front.   The occipital ring is sometimes mesially thickened.   Three or four pairs of furrows are on the glabella which become confluent, when depressed, and especially so in the posterior ones.

Free cheeks are broad and fixed cheeks narrow and provided with short genal spines.   The palpebral lobe and ridge describe a quarter of a large circle.   The frontal limb and rim are both convex, the former being a little longer than the latter.

The hypostoma of *P. lantenoisi* is elongate, strongly convex, marginated by a narrow border and expanding anteriorly into triangular wings.   That of *F. blayanci* which appears to be prolonged secondarily, has a less rounded posterior outline.

The thorax is composed of 14 or about 14 segments.   The pygidium known of *lantenoisi*, *deprati* and *tingi*, is very small. Its axial furrows are very shallow; axial lobe is broad and provided with one or two rings; lateral lobe about half as wide as the axis and grooved by an incurved shallow furrow; marginal border narrow and flat.   Test is smooth except "*Protolenus*" *pustulatus* COBBOLD.

Merit to LU (1942) some growth stages of *P. deprati* were brought to light. (See text-fig. 7).   The protaspid (fig. a, 0.5× 0.68 mm.) has a large subcircular frontal lobe behind which there are at least three segments. Starting from the lateral sides of the frontal lobe, the palpebral lobes extend along the margin of the shield.
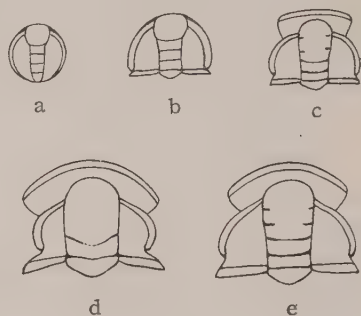

Figure 7.   Ontogeny of *Palaeolenus deprati* MANSUY (After LU, 1942).

a.   Ca 0.5 mm. long. ×14
       Anaprotaspid
b.   0.7 mm. long. ×14
       Metaprotaspid (?)
c.   1.6 mm. long. ×7
       Meraspid
d.   4 mm. long. ×4
       Early Holaspid cranidium
e.   5.5 mm. long. ×3
       Holaspid cranidium.

The second (fig. b, 0.66 mm. long) may be a metaprotaspid cephalon and the third (fig. c, about 1.6 mm.) a meraspid cranidium. Through these stages the frontal lobe becomes relatively small. The glabellar furrows become discrepant from the anterior ones and the frontal limb appears.

In the early holaspid cranidia (figs. d–e, 4 to 5.5 mm.) the occipital ring is thickened mesially and the anterior facial sutures are more widely divergent than those of the full grown forms.

Distribution:—In Yunnan *Palaeolenus* occurs in the lower *Redlichia chinensis* beds for which *Palaeolenus* zone was proposed. It is found together with *Redlichia* cfr. *cylindrica* in South Korea. In Herault, South France it is known from the limestone at the top of the Lower Cambrian beneath the shale containing *Paradoxides rouvillei, Conocoryphe heberti* and others. In England it occurs in the *Eodiscus bellimarginatus* limestone of Comley.

Palaeolenus aotii KOBAYASHI, new species

Plate XIII, Figures 1–5.

Description:—Cranidium wide, subquadrate; glabella convex, elevated above cheeks, wider than fixed cheeks, long, nearly parallel-sided, but more or less expanding forward and subrounded in front; three pairs of glabellar furrows disconnected, but the fourth pair are confluent on axis; occipital furrow running across glabella; occipital ring expanded mesially; palpebral lobe long, occupying almost posterior half of fixed cheek and united with glabella by a slightly oblique eye-ridge; preglabellar area narrow, inclined forward; frontal limb a little broader than frontal rim; shallow marginal groove interplaced between them. Free cheek narrow, provided with a short genal spine. Facial sutures long and subparallel in front of eyes and short and diagonal behind them. Surface smooth.

Comparison:—On account of the relative breadth of the glabella and cranidium this species appears closer to *P. pustulatus* than *P. deprati*. The frontal limb is narrower in this than in *P. blayanci* and *P. pustulatus*.

Occurrence:—Lower Cambrian limestone at Ma 26 where it is accompanied by *Redlichia* cfr. *cylindrica*.

Subfamily Aldonaiinae HUPÉ, 1952

The subfamily was proposed by HUPÉ, to include *Aldonaia* LERMONOTOVA, 1940, (Fig. 6f) and *Rinconia* HUPÉ, 1952. POKROVSKAYA (1959) referred his two new genera, *Tuvanella* and *Eleganolimba* to the subfamily where the latter has narrow but distinct ridges radiating from the front of the glabella and oblique palpebral ridges. The former bears a preglabellar boss and resembles *Inouyia*, s. str. but the frontal furrow and rim are quite distinct and very long. While the above genera are all Lower Cambrian, TCHERNYSHEVA added Middle Cambrian *Volonellus* IVSHIN (1953) (Fig. 6g) to them. Except *Rinconia* from

Andalusia, Spain, all others are known from Central or Northern Asia.

Order Corynexochida KOBAYASHI, 1935

The Corynexochida were first proposed to include seven families in addition to ten subfamilies, all having long glabellae, as follows:

1. Corynexochidae { Corynexochinae
                     Dolichometopinae

2. Komaspidae

3. Oryctocephalidae { Oryctocephalinae
                      Dorypyginae

4. Pagodidae

5. Damesellidae { Damesellinae
                   Dorypygellinae
                   Kaolishaninae

6. Lloydidae

7. Loeistegidae { Eochuanginae
                   Leiosteginae
                   Illaeninae

Subsequently WHITEHOUSE (1939) added the Asaphidae and Ceratopygidae to the Corynexochida and referred the Pagodidae to his Ellipsocephalida. Still later the Komaspidae, Pagodiidae, Damesellidae, Lloydidae and Leiostegiidae were transferred from the Corynexochida to the Ptychopariida or his Conocoryphacea by HENNINGSMOEN (1951). Accepting this view, HARRINGTON et al. (1959) restricted the Corynexochida to seven families as follows:

1. Dorypygidae KOBAYASHI, 1935
2. Ogygopsidae RASETTI, 1951
3. Oryctocephalidae BEECHER, 1897
4. Dolichometopidae WALCOTT, 1916
5. Corynexochidae ANGELIN, 1854
6. Zacanthoididae SWINNERTON, 1915
7. Dinesidae LERMONTOVA, 1940

As pointed out recently (1960), however, the dameselloids and leiostegioids are two groups of trilobites most flourished in the Asio-Pacific province where no form is found to link with ptychoparioids. Not only these two groups, but the Corynexochida as a whole may be said an Asio-Pacific group of trilobites whose representation in the Atlantic province is rather exceptional. Naturally much remains to be explored in the vast terrain of Asiatic continent as well as the Pacific province. Through the active explorations in recent years new corynexochoids were discovered from time to time in Central and Northern Asia and other areas and many new genera and some new families were erected for them. SUVOROVA and TCHERNYSHEVA (1960) grouped 9 families in the order as follows:

1. Jakutidae SUVOROVA, 1960
2. Dolichometopidae WALCOTT, 1916

3. Amgaspidae TCHERNYSHEVA, 1960
4. Edelsteinaspidae HUPÉ, 1953
5. Zacanthoididae SWINNERTON, 1915
6. Corynexochidae ANGELIN, 1854
7. Triniidae POLETAYEVA, 1956
8. Dorypygidae KOBAYASHI, 1915
9. Oryctocephalidae BEECHER, 1897

It is further undeniable that the Namanoiidae LERMONTOVA, 1951 are quite intimate to the Jakutidae and the Eoacidaspidae POLETAYEVA, 1956 to the Amgaspidae. I have already discussed the Dolichometopidae (1942), Komaspidae (1954) and Damesellidae (1941-42, 56, 60) in a great detail and the Dorypygidae, Leiostegiidae and Pagodiidae (1960) to some extent. Here I wish to give some comments on the other families and emend the classification of the order on the basis of the present knowledge.

The Dorypygidae and Dolichometopidae are two of the typical families of this order which range from the Lower to the Upper Cambrian, although most flourished in the Middle Cambrian period. The Corynexochidae consist of small trilobites intimate to these families. Previously the Lower and Middle Cambrian Zancanthoididae were considered closer to the redlichioids rather than the corynexochoids, but with new materials RASETTI has shown an almost continuous series of genera bridging the gap between *Zacanthoides* and *Bathyuriscus*. He pointed further that the Ogygopsidae indicate a Middle Cambrian shoot intermediate between the Dorypygidae and Dolichometopidae.

How to define the Dinesidae is a question, but *Dinesus* or the Dinesidae s. str. appear more related to the corynexochoids than other trilobite groups. The triangular basal side-lobes of the glabella which are characteristic of *Dinesus* are often met with in the Erbiopsinae of the Dorypygidae.

Oryctocephalites reveals close alliance to the Dorypygidae in the general aspects of the cranidium, but the pitted glabellar furrows are speciality of the Oryctocephalidae rare among the corynexochoids. In the broad fixed cheeks the family agrees better with the Jakutidae and the allies than the above mentioned families.

The Jakutidae as well as the Namanoidae are the Lower Cambrian families of Siberia which have the forwardly tapering glabella and the broad fixed cheeks. The breadth is especially different in the preocular part of the cheek which is strikingly narrower in the Dolichometopidae or the Dorypygidae than in these families. Nevertheless the close affinity between the Dolichometopidae and the Jakutidae can hardly be overlooked in the comparison between *Parapoliella* of the former and *Judaiella* of the latter family. The Namanoidae comprise a group of small trilobites like the Pagodiidae.

It is quite probable that the Eoacidaspidae were specialized in the Middle and late Upper Cambrian from *Judaiella* like trilobites through the Middle Cambrian Amgaspinae. The Edelsteinaspidae represent a Middle Cambrian branch of the same group which is characterized by the cylindrical glabella with chevron-shaped furrows and other aspects.

There is a wide time gap between the ranges of the Jakutidae and Leostegiidae to involve many missing links. Nevertheless it can hardly be overlooked morphologically that *Jakutus* bears many common characters with *Chuangia*. The occurrence of *Girandia* in the late Middle Cambrian of Central Siberia suggests the boreal origin of the Leiostegiidae.

It is further interesting for me to see that *Chakassikia* is placed in the Dorypygidae and *Inouyina* in the Namanoidae by SUVOROVA and TCHERNYSHEVA (1960) because I thought *Chakassikia* and *Inouyina* as ancestral forms of the Damesellidae.

They agree with me in referring the Bathynotinae to the Komaspidae. *Bathynotellus* (*B. yermolaevi* LERM. Fig. 8v) of the Bathynotinae, however, shows high specialization of the subfamily in the Lower Cambrian period. How far the Komaspidae were removed from the Jakutidae and other corynexochoid families is of course a problem. On the other hand it is certain that some families have been branched off from the Corynexochida already in the Lower Cambrian period.

Family Corynexochidae ANGELIN, 1854

This family is so far unrepresented in Eastern Asia and probably also in Southern Asia. *Corynexochus* sp. from Kashmir (REED, 1934, pl. 2, fig. 16) is represented by pygidia which belong probably to either *Tonkinella* or *Amphoton*. The family is represented in Northern and Central Asia by *Corynexochus*, *Corynexochina* and *Trinia*.

Subfamily Corynexochinae ANGELIN, 1954

This subfamily includes *Bonnaspis*, *Corynexochina* and *Vanuxemella* and probably *Hanburia*, beside *Corynexochus*. As the history of *Corynexochus* was reviewed in detail by LAKE (1934), *Karlia* WALCOTT, 1880, founded on *K. minor* WALCOTT, is generically inseparable from *Corynexochus*, but it was pointed out that *Karlia stephenensis* WALCOTT which agrees with the diagnosis of *Karlia* is distinct from *Corynexochus* in the posterior and lateral position and smaller size of the eyes and the relatively large pygidium. LAKE, however, had left its denomination to RESSER (1936) who called the genus *Bonnaspis*.

Vanuxemella WALCOTT, 1916 (i. e. *Vistoia* WALCOTT, 1925) is located in the Zacanthoididae by some authors (1959), but it is much more reasonable to consider a corynexochid whose two or three posterior segments of thorax are caudalized. Otherwise it coincides with the Corynexochinae. Because the closest ally of *Hanburia* is probably *Vanuxemella*, it may be a member of this subfamily rather than to be tied up in any other group.

Genus *Corynexochina* LERMONTOVA, 1940

The type species is *Corynexochina weberi* LERMONTOVA, 1940, (Fig. 8a-b) from the Middle Cambrian of South Ferghana. The second species is *Coryne-*
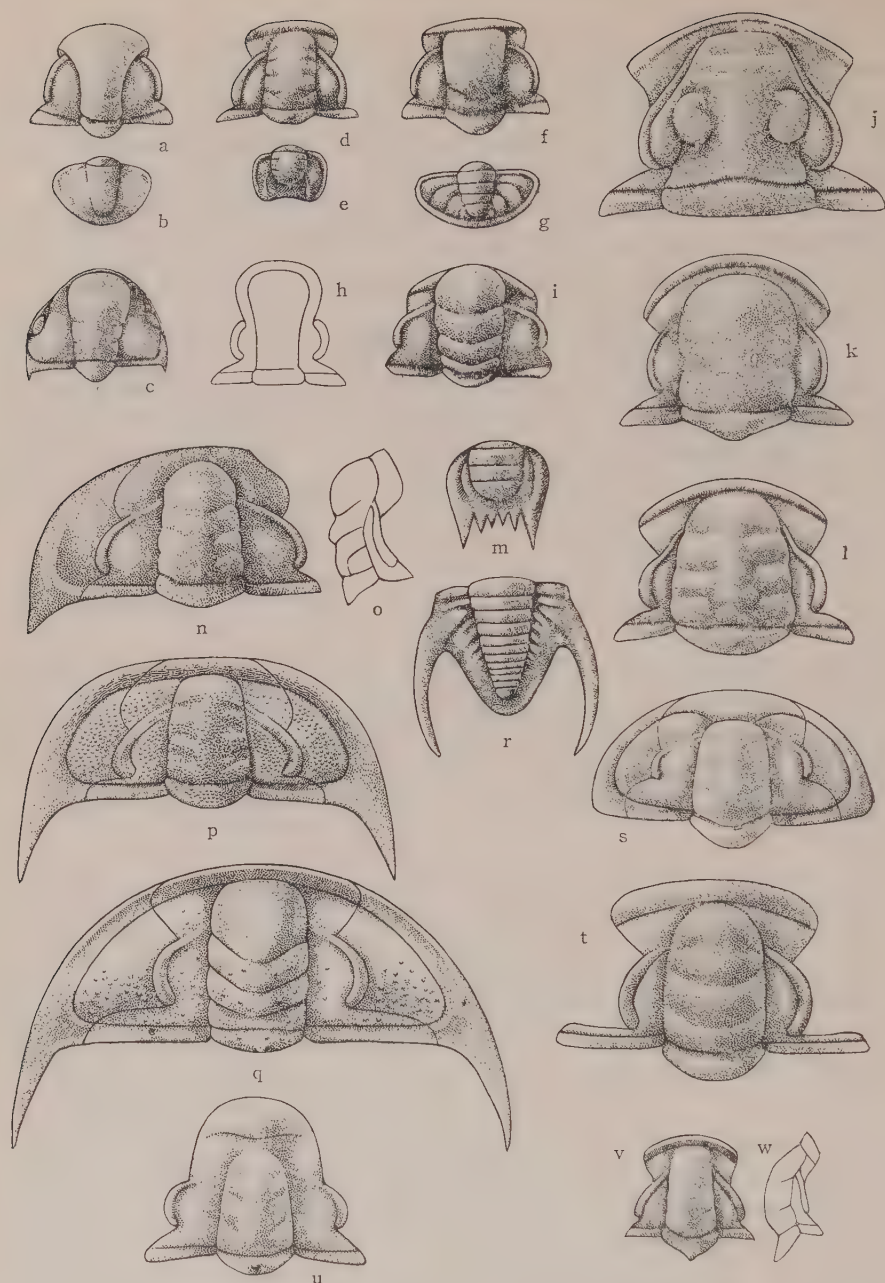
Figure 8. Corynexochida and similar trilobites.

a–b. *Corynexochina weberi* LERMONTOVA
c. *Trinia bella* POLETAYEVA
d–e. *Parapoliella obrutchevi* (LERMONTOVA)
f–g. *Poliellaspis sayanicus* (POLETAYEVA)
h. *Amphoton microlops* KOBAYASHI
i. *Erbiopsis grandis* LERMONTOVA
j. *Eoacidaspis salairensis* POLETAYEVA
k. *Belovia calva* TCHERNYSHEVA
l. *Amgaspis medius* TCHERNYSHEVA

m. *Oryctocephalops frischenfeldi*
                                    LERMONTOVA
n–o. *Nodiceps onerosa* SUVOROVA
p. *Jakutus quadriceps* LERMONTOVA
q. *Edelsteinaspis ornatus* LERMONTOVA
r. *Bathynotellus yermolaevi* LERMONTOVA
s. *Namanoia namanensis* LERMONTOVA
t. *Bathyuriscellus robustus* LERMONTOVA
u. *Fabulaspis famosus* IVSHIN
v–w. *Malykania grikovae* SUVOROVA

xochina asiatica IVSHIN, 1953, from the Middle Cambrian of Kazakstan. The diagnosis of the genus runs as follows :

Small trilobites resembling *Corynexochus*, but most furrows on the cranidium and pygidium are effaced. These obsolete furrows are, however, still internally impressed and therefore distinct on exfoliated surface.

Subfamily Acontheinae WESTERGAARD, 1950

This subfamily was erected for *Acontheus acutangulus* ANGELIN from the *Solenopleura brachymetops* zone of Scania, Sweden, by virtue of the lack of eyes and facial sutures.

Subfamily Triniinae POLETAYEVA, 1956

The taxonomic position was uncertain of the Triniidae, but in my opinion it indicates a branch of proparian corynexochids having large pear-shaped glabellae and subtrigonal fixed cheeks.

Genus *Trinia* POLETAYEVA, 1956

Diagnosis :—Small proparian trilobites ; cranidium subtriangular, broad at base, rounded anteriorly ; glabella pear-shaped, somewhat contracted at rear, twice broadened in front, strongly vaulted, abruptly slant and overhanging in front ; dorsal furrows profound and forwardly divergent ; fixed cheek subtrigonal, two-thirds as long as glabella, swelling up, but not so high as glabella and bordered by narrow rim which tails out at glabella ; eyes small, convex, at anterior half of cheek ; eye-ridge absent ; facial suture short, descending forward from eye and cutting frontal rim of cranidium near glabella ; behind eye the suture directed outward and cutting lateral margin in front of genal angle ; occipital ring thick, broad and more or less conical and pointed behind ; occipital furrow deep and distinct ; posterior border narrow and high ; genal angle pointed back into a short spine ; surface with fine reticulae.

Type-species :—*Trinia bella* POLETAYEVA (Fig. 8c) from late Middle Cambrian of Salair, West Siberia. Two pairs of very short and weak lateral furrows are discernible in the posterior part of the glabella of this species.

Family Dolichometopidae WALCOTT, 1916

This family include seven Asiatic genera as follows :
1. *Amphoton* LORENZ, 1906
2. *Fuchouia* RESSER and ENDO in KOBAYASHI, 1935
3. *Poliellina* POLETAYEVA, 1936
4. *Poliellaspis* LERMONTOVA, 1940
5. *Amphotonella* KOBOYASHI, 1942
6. *Sunia* KOBAYASHI, 1942
7. *Parapoliella* TCHERNYSHEVA, 1956

Amphoton, Fuchouia and *Sunia* were thought indigenous to Eastern Asia,

but the first of these is known to have been flourished in Australia. The three
others of the above six genera are all North Asiatic. Brief notes are given
here only on *Poliellaspis* and *Parapoliella* which were not included in my re-
vision of this family in 1942.

Olenoides obrutchevi LERMONTOVA, 1925, (Fig. 8d-e) and *Poliellina sayanicus*
POLETAYEVA, 1936, (Fig. 8f-g) are respectively the type-species of *Parapoliella*
TCHERNYSHEVA, 1956 and *Poliellaspis* LERMONTOVA, 1940. As they have been
considered congeneric with *Poliellina laermonthovi* POLETAYEVA, 1936, the type-
species of *Poliellina*, they are all intimately related to one another (1942, 43).
The glabella is contracted in the middle in *laermonthovi* as well as *sayanicus*.
It is, however, more expanded anteriorly in the former and posteriorly in the
latter. Only the posterior and occipital furrows are impressed and others ob-
solete in the latter. The frontal border is straight in the latter but arcuate
in the former. In the former and also in *obrutchevi* all lateral furrows are
distinct. The glabella is not contracted but parallel-sided in *obrutchevi*. The
axial lobes of the thorax and pygidium are narrower in *laermonthovi* than the
two others. The pygidium of *laermonthovi* is subtriangular, whereas it is
subelliptical and well rounded in *obrutchevi*.

Genus *Amphoton*, LORENZ, 1906

Amphoton spinula KOBAYASHI

Plate XII, Figures 19 and (?) 18.

1942. *Amphoton derceto* (WALCOTT) var. *spinula* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ.
    Tokyo, Sec· 2, Vol. 6, Pt. 10, p. 198.*
1942. *Amphoton derceto* (WALCOTT), var. *spinula* KOBAYASHI, *Jour. Geol. Soc. Japan,
    Vol. 49, p. 474, pl. 18, figs. 12–13.*

This species resembles *Amphoton parallela* ENDO and RESSER, 1937, very
closely, but differs in the greater elevation and backward tapering of the gla-
bella, pronounced lateral furrows and arcuate frontal border. Here this species
is excluded from *A. derceto* by the reason that the preocular part of the fixed
cheek is much broader in this species. It is especially so in the crandium in
fig. 18 which is compressed in the axial trend.

Occurrence:—Division 2 (?) of Majo or Masong formation ; Ma 32, Ama 272
and (?) Ma 23.

Amphoton microlops KOBAYASHI

Text-figure 8h.

1942. *Amphoton microlops* KOBAYASHI, *Jour. Geol. Soc. Japan, Vol. 49, p. 474, pl. 18, fig.
    11.*
1942. *Amphoton microlops* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 6,
    Pt. 10, p. 198.*

This is represented by an unusually flat cranidium whose glabella is long
and expanded remarkably in its anterior part. Lateral furrows cannot be
seen, but dorsal furrows are well marked. The eyes are relatively large and

located close to the posterior of the glabella. The fixed cheek is very narrow.

Occurrence:—Division 3 of Kanairi or Hanaeri formation; Kan 3.

<div align="center">

Family Dorypygidae KOBAYASHI, 1935

Genus *Kootenia* WALCOTT, 1888

Kootenia amanoi KOBAYASHI, new species

Plate XII, Figures 25-30, (?) 31.

</div>

This species has the cranidium closely allied to that of *Kootenia punctata*, but the latter has a strong pit at the antero-lateral angle of the glabella and has a sharp spine on the occipital ring. Eyes are somewhat larger and located at the points a little more posterior. The cranidium in fig. 27 appears to bear very fine tubercles on the surface, but the test looks smooth on the other specimens.

The associated free cheek in fig. 28 has a relatively thick lateral border which is protruded into a short genal spine. The pygidium is nearly twice as broad as long. The axis is composed of three rings and a large terminal lobe. The axial lobe is almost as broad as the pleural one exclusive of the marginal border and divided into ribs by three furrows. The border is moderate in breadth, depressed and limited by a furrow on the inner side. The pleural rib is broad and protruded beyond the border into a spine which is flattopped, short and varies in size. It is fairly large on the pygidium in figs. 29a–b, but very tiny in the other in fig. 25. Such spines are countable 5 on each side of the shallow post-axial sinuation.

Occurrence:—Ma 23, N2 and Ama 273. The crandium from Kan 2 (fig. 31) is so strongly deformed that its anterior part is drooping vertically.

<div align="center">

Subfamily Erbiopsinae KOBAYASHI, nov.

</div>

Diagnosis:—Dorypgidae having large subtriangular pygidia with entire margins. A pair of triangular lobes sometimes present in the two sides of the glabellar base and another pair opposed at the anterior of the glabella.

Remarks:—*Erbiopsis* LERM. 1940 founded on *Erbiopsis grandis* LERM. (Fig. 8i) is a puzzling genus, referred with query to the Proerbiidae HUPÉ, 1953, by HUPÉ, to the Dorypygidae by HARRINGTON et al. (1959), and to the Dinesidae LERM. 1940, by SUVOROVA and TCHERNYSHEVA (1960). In erecting two genera, *Erbiopsidella* and *Rondocephalus*, POKROVSKAYA (1960) located them in the Dolichometopidae together with *Erbiopsis*. In the bulbous glabella protruding forward they are more related to the Dorypygidae than the Dolichometopidae and quite distinct from the Dinesidae, Proerbiidae or Tollaspidae KOBAYASHI (1943).

Erbiopsidella is, however, allied to *Dinesus* in the isolated triangular basal side-lobes of the glabella as well as triangular lobes on the two sides of the glabellar front. Its associated pygidium has an entire margin and is very much like that of *Erbiopsis*. The antero-lateral triangular lobes appear absent

in the two other genera, but the basal side lobes are clearly defined in *Rondocephalus* and three lateral furrows are all strongly impressed in *Erbiopsis*. Therefore the three genera seem to constitute a solid group which is intermediate between the Dorypygidae and Dinesidae. For this group a new subfamily, Erbiopsinae is proposed in the Dorypygidae. It is improbable that the Dinesidae were derived from this subfamily, because the three genera appear more specialized in the outline of the glabella than the Dinesidae.

Family Oryctocephalidae BEECHER, 1897

Subfamily Lancastriinae KOBAYASHI, 1935

Oryctocephalidae with archaepygidium

Lancastria KOBAYASHI, 1935 (Type-species: *Olenopsis roddyi* WALCOTT). Lower Cambrian; eastern North America.

Subfamily Oryctocephalinae BEECHER, 1897

Oryctocephalidae with spiniferous pygidium

Oryctocephalus WALCOTT, 1886. (*Oryctocephalus primus* WALCOTT). Middle Cambrian; western North America, Siberia, North Korea and Himalaya (Spiti).

Oryctocephalites RESSER, 1939. (*Oryctocephalites typicalis* RESSER). Middle Cambrian; western North America.

Oryctocephalops LERMONTOVA, 1940. (*Oryctocephalops frischenfeldi* LERMONTOVA, Fig. 8m). Middle Cambrian; Siberia (Anabar).

Oryctocephalina LERMONTOVA, 1940. (*Oryctocephalina reticulata* LERMONTOVA). Middle Cambrian; Siberia (Anabar).

Vinakainella RUSCONI, 1952. (*Oryctocephalus* (*Vinakainella*) *asperoensis* RUSCONI, 1952. Middle Cambrian; Argentina.

Subfamility Tonkinellinae REED, 1934

(Oryctocarinae HUPÉ, 1953)

Oryctocephalidae with entire pygidium.

Oryctocare WALCOTT, 1908. (*Oryctocare geikiei* WALCOTT). Middle Cambrian; western North America and Siberia (Anabar).

Tonkinella MANSUY, 1916. (*Tonkinella flabelliformis* MANSUY). Middle Cambrian; Caracorum, Himalaya (Kashmir), Indochina (Yunnan-Tonkin border), Korea, Shantung and western North America.

Arthricocephalus BERGERON, 1899. (*Arthricocephalus chauveaui* BERGERON). Lower Cambrian; South China.

? *Cheiruroides* KOBAYASHI, 1935. (*Arthricocephalus primigenius* SAITO). Lower Cambrian; North China (Laiotung) and North Korea.

According to LU (1957) *Arthricocephalus* has distinct eye-ridges, 7 thoracic segments and interpleural furrows and the marginal border of the pygidium is rudimentary. In *Tonkinella* only 5 segments are countable on the thorax of

T. stephenensis KOBAYASHI (RASETTI, 1951).

Cheiruroides orientalis has no less than 14 segments in thorax. It is allied to *Sinolenus* on one side and to *Arthricocephalus* and *Tonkinella* on the other, (KOBAYASHI and KATO, 1951).

Family Jakutidae SUVOROVA, 1959

The family typified by *Jakutus* LERMONTOVA, 1951 (*J. quadriceps* LERM. Fig. 8q) includes corynexochoids similar to the Dolichometopidae, but the glabella is gradually tapering forward. The eyes of medium size are confluent with wide oblique eye-ridges; facial sutures divergent forward from the eyes; anterior fixed cheek much larger than in the Dolichometopidae; free cheek with a genal spine; thoracic pleura ending at a spine; pygidium small.

Bathyuriscellus LERMONTOVA, 1951, (*B. robustus* LERM., Fig. 8u), *Judaiella* LERMONTOVA, 1951 and *Malykania* SUVOROVA, 1958, (*M. grikovae*, SUVOROVA, Figs. 8s-t) are referred to the family by SUVOROVA. The thorax is composed of 17 segments in *Judaiella vermicula* LERMONTOVA. All the four genera are distributed in the Lower Cambrian of Siberia.

Family Edelsteinaspidae HUPÉ, 1953

Edelsteinaspis ornatus LERMONTOVA, 1940, (Fig. 8p) from the early Middle Cambrian of Minussinsk, Siberia which is most typical of the family has the long subcylindrical glabella like the Dolichometopidae and the large preocular part of the fixed cheek like the Jakutidae. The three chevron-shaped furrows on the glabella and the broad postero-lateral limb of the fixed cheek are the features not seen in these families. The thorax consists of 14 segments; pygidium subelliptical; its narrow axis composed of 7 rings and a terminal lobe; pleural part with double ribs; marginal border more or less depressed.

Labradoria RESSER, 1936, *Nodiceps* SUVOROVA, 1959 (*N. onerosa* SUVOROVA, Fig. 8n-o) and *Paleofossus* POKROVSKAYA, 1960, were added to the family respectively by IVSHIN (1957), SUVOROVA (1959) and POKROVSKAYA (1960). In parallel anterior sutures and other aspects *Labradoria* looks to me more likely a protolenid close to *Sinolenus*. In the forward tapering of the glabellar outline *Nodiceps* agrees better with the Jakutidae than the Edelsteinaspidae. In *Paleofossus* the frontal lobe of the glabella is distinctly conical and only the posterior furrows describe V. In the obliquity of the lateral furrows *Laticephalus* POKROVSKAYA, 1960, reveals better agreement with *Edelsteinaspis*, but the eyes are much smaller and the fixed cheeks behind them incomparably larger.

Family Namanoiidae LERMONTOVA, 1951

Namanoia LERMONTOVA, 1951, is a small trilobite having a convex marginal border which is protruded behind in front of the glabella, like in certain genera of the Ordosiinae. Thorax composed of 10 to 12 segments and pleural

ends acute. Pygidium lenticular and 5-segmented; pleural and interpleural furrows running into narrow depressed border. *Namanoia namanensis* Lerm. 1951 (Fig. 8r) from the *Protolenus* zone of the Namana river, west Yakutsk, Siberia is monotypic. It appears to indicate a subparallel branch to the Ordosiinae of the Pagodiidae, but there is no link between them.

Recently Tchernysheva and Suvorova referred *Inouyina* Poletayava, 1936, *Kassinus* Ivshin, 1953, (?) *Inouyellaspis* Ivshin, 1953 and (?) *Fabulaspis* Ivshin, 1953. As I have previously placed the first of them in the Damsellidae, the Namanoidae may be related to the Damesellidae as well as the Pagodiidae. It is a question for me that the three other genera are very close to the Namanoidae.

Family Eoacidaspididae Poletayeva, 1957

Amgaspis Tchernysheva, 1956, (*A. medius* Tchernysheva, Fig. 8l) from the late Lower and early Middle Cambrian of Siberia and Altai for which the author (1960) erected a new family, Amgaspidae, is intermediate in character between the Jakutidae and Eoacidaspidae. In the Jakutidae *Judaniella* is the closest to *Amgaspis*, but the glabella is larger and more oval and the fixed cheek narrower and the eyes are located more posterior in *Amgaspis* than *Judaiella*. In the latter two aspects *Amgaspis* agrees better with *Acidaspides* than *Judaiella*.

The Eoacidapididae Poletayeva, 1957, comprise *Eoacidaspis* Poletayeva, 1956, (*E. salairensis* Poletayeva, Fig. 8j) from the Upper Cambrian of Siberia, *Belovia* Poletayeva, 1956, (*B. calva* Poletayeva, Fig. 8k) from the late Middle Cambrian of Siberia and probably *Acidaspides* Lermontova, 1951, from the late Middle Cambrian of Siberia and Upper Cambrian of Kazakstan. Compared to *Acidaspides*, the glabella is more expanded in the anterior half and the dorsal and glabellar furrows are more obliterated in *Belovia*. In *Eoasidaspis* on the contrary, the glabellar configuration is considerably elaborated. *Acidaspides* is referred to the Odontopleuridae by Maxinova (1960), but it requires a further confirmation.

It is interesting for me to see that *Acidaspides* is intermediate between *Amgaspis* on one side and *Belovia* and *Eoacidaspis* on the other not only morphologically but also in the geological age. In my opinion the difference of *Amgaspis* from the three others may be no more than the subfamily rank. It is probable further that the Eoasidaspidae were derived from the Jakutidae in the neighbourhood of *Judaiella* through the Amgaspinae.

Order Ptychopariida Swinnerton, 1915

Family Ptychopariidae Matthew, 1887

Genus *Ptychoparia*, s. l.

" *Ptychoparia* " aff. *impar* Walcott,

Plate XII, Figures 12-13.

1905. aff. *Ptychoparia impar* WALCOTT, *Proc. U. S. Nat. Mus. Vol. 29*, p. 78.
1913. aff. *Ptychoparia impar* WALCOTT, *Cambrian Faunas of China*, p. 131, pl. 12, figs.
9, 9a.

The conical glabella, weak lateral furrows, fairly large eyes, depressed frontal border and subparallel anterior sutures are combined to show the close resemblance of the cranidia to that of *Ptychoparia impar*. The resemblance is especially close for the cranidium in fig. 12, of which posterior part is unfortunately ill-preserved. The other in fig. 13 is obliquely compressed, yielding strong lateral furrows. Probably due to the secondary elongation, this looks taller. The furrows are quite oblique in this cranidium, while they are transversal in *P. impar*.

Occurrence:—Ma 12.

" *Ptychoparia* " α sp. indt.

Plate XII, Figure 14.

This cranidium has a convex subsquare glabella of medium size, bordered by deep axial furrows. Two short but deep lateral furrows are present. The occipital furrow is deep and the occipital ring more or less thickened in the middle. The fixed cheek is as broad as the glabella; eyes of medium size at the mid-length of the cranidium; eye-ridge crossing the cheek faintly. A frontal rim is slightly narrower and more strongly convex than the frontal limb. A facial suture anterior to the eye appears to be parallel to the axis and intramarginal for a short distance on the marginal border.

The broad fixed cheek, transversal eye-ridge and some other features show its resemblance with ptychopariids, but the glabella has a square outline. It is somewhat similar to *Lioparella* ? *longifrons* (KOBAYASHI), 1935, but its frontal limb is much shorter and more convex.

Occurrence:—Kan 3.

" *Ptychoparia* " β sp. indt.

Plate XIII, Figures 9-10.

Ptychopariid with broad strongly convex cranidium. It is more or less similar to *Ptychoparia acilis* WALCOTT from the Shihchiao stage of Shantung, but differs from that species by its more conical and convex glabella and strongly convex frontal limb. The lateral furrows are obsolete on the glabella, but the eye-ridge is distinct. It has no occipital spine. The anterior facial suture runs nearly parallel to the axis and then curves inward in crossing the border.

Occurrence:—*Metagraulos sampoensis* zone of Samposan or Sambangsan formation at locs. 316 and 317.

Family Olenidae BURMEISTER, 1843

Subfamily Papyriaspinae WHITEHOUSE, 1939

Hedinaspis, or *Hedinia* TROEDSSON, 1937, non NAVAS, 1936, was erected as an olenid genus. Subsequently in 1939 WHITEHOUSE instituted Papyriaspinae in the Olenidae to include *Pianaspis* SAITO and SAKAKURA, 1936, *Papyriaspis* WHITEHOUSE, 1939 and *Rhodonaspis* WHITEHOUSE, 1939, beside *Hedinaspis*. HENNINGSMOEN (1957) excluded these four genera from the Olenidae which he traced back to the neighbourhood of the late Middle Cambrian *Andrarina costata* (ANGELIN), as previously suggested by WESTERGAARD (1922). In Treatise (1959), the Papyriaspidae are accepted by POULSEN and HENNINGSMOEN as a family of the Olenacea. Because the Papyriaspidae represent the Asio-Australian branch in the middle and late Cambrian period, it is likely a parallel to the Upper Cambrian Olenidae.

Genus *Hedinaspis* TROEDSSON, 1951

1937. *Hedinia* TROEDSSON, *Pal. Sinica, N. S. B, No. 2*, p. 56.
1953. *Hedinia* HUPÉ, *Ann. de Pal. tom. 39*, p. 173.
1951. *Hedinaspis* TROEDSSON, *Geol. Foren. Forhandl. Bd. 73*, H. 4, p. 695.
1957. *Hedinaspis* LU, in *Index Fossils of China, Invert. vol. 3*, p. 277.
1959. *Hedinaspis* POULSEN, in *Treatise of Invert. Pal. 0-1*, p. 269.

Type-species:—Hedina regalis TROEDSSON, 1937.

The sea-connection between Central Asia and South Korea pointed out in 1944 by means of this genus, is now further confirmed by the find of *Hedinapsis* in Chekiang and Kueichou and the description of *H. kueichouensis* LU, 1954.

Hedinaspis cfr. *regalis* (TROEDSSON)

1937. cfr. *Hedinia regalis* TROEDSSON. *The Sino-Swedish Expedition Publ. 4*, p. 56, pl. 3, fig. 5, pl. 7, figs. 1-5, 7-11, pl. 8, fig. 38.
1942. *Hedinia* cfr. *regalis* KOBAYASHI, and AOTI, *Proc. Imp. Acad. Tokyo, Vol. 18*, p. 305.
1944. *Hedinia regalis* KOBAYASHI, *Ibid. Vol. 20*, p. 102, text-figs. a-c.
1951. cfr. *Hedinaspis regalis* TROEDSSON, *Geol. Foren, Forhandl. Bd. 73, Hft. 4*, p. 695.
1954. cfr. *Hedinaspis regalis* (TROEDSSON) in LU, *Acta Pal. Sinica, Vol. 2, No. 2*, pl. 3, fig. 5.

According to LU (1954), *Hedinaspis kueichouensis* differs from *H. regalis* in that "the glabella is relatively shorter, the anterior branches of the facial sutures are more strongly curved (so as to make the antero-lateral corners of the cranidium more rounded) and the ridges bounded in each side of the thoracic pleurae are very narrow, thread-like." In the strength of the pleural ridge the Bunkei specimen agrees better with *regalis* than *kueichouensis*.

*Occurrence:—*Kan 3.

Family Solenopleuridae ANGELIN, 1854

Genus *Solenoparia* KOBAYASHI, 1935

Solenoparia (?) *bisulcata* KOBAYASHI, new species

Plate XIII, Figure 13.

This species is well characterised by its relatively broad cranidium, bulbous glabella provided with two pairs of distinct oblique lateral furrows and a transverse occipital furrow, elevated palpebral lobe, depressed frontal limb and straight frontal rim. The palpebral lobes are medium in size, opposed at the middle of the glabella and connected with the latter by eye-ridges.

This species is combined with *Anomocarella subrugosa* (WALCOTT), *Anomocarella thraso* (WALCOTT) and probably with *Ptychoparia talingensis* (DAMES) in a group which is somewhat distinct from typical *Solenoparia* in the anterior outline of the glabella which is not so rounded as in *S. toxeus*. Two pairs of lateral furrows and the eye-ridges are not completely effaced in them. These furrows are strongly impressed in this species.

Occurrence:—*Metagraulos sampoensis* zone of Samposan or Sambangsan formation at loc. 317.

Family Agraulidae RAYMOND, 1913

Genus *Mungyongia* KOBAYASHI, new genus

The subovate, gently convex cranidium, relatively short, truncate-conical unfurrowed glabella, thick neck ring, fixed cheek of moderate breadth, extraordinarily large eyes, and long preglabellar field are the characteristics of this genus. Its closest ally may be *Metagraulos* from which it differs in the smaller and more conical glabella and much larger eyes.

Type species:—*Mungyongia tulipiformis* KOBAYASHI, new gen. and sp.

Mungyongia tulipiformis KOBAYASHI, new gen. and species

Plate XIII, Figure 11.

The glabella exclusive of the neck ring is only a little longer than the preglabellar area. It is very prominent; its outline breviconic, truncated in front; dorsal furrow profound; neck ring thick and depressed. The fixed cheek is almost as wide as the glabella measured in the anterior; eye-band thick and almost as long as the glabella; facial sutures convergent from the eyes to the transverse frontal margin. Test smooth.

Occurrence:—*Nisusia* limestone at Am 272.

Mungyongia subovalis KOBAYASHI, new gen. and species

Plate XIII, Figure 10.

This species differs from the preceding primarily in the glabella which is in the same doming level with the cheeks. Secondarily, its occipital ring is thicker than that of the preceding. The ring merges with the posterior

lobe in the holotype cranidium, the aspect being very unusual, but probably
due to the obscurity of the incision at the boundary caused by the lateral com-
pression.

Occurrence :—Nisusia limestone at Ma 32.

Genus *Metagraulos* KOBAYASHI, 1935

Metagraulos sampoensis KOBAYASHI, new species

Plate XIII, Figures 5-8.

*Description :—*Cranidium subquadrate, but its frontal margin is well round-
ed ; glabella truncate-conical, bordered by strong dorsal furrows, very convex
and highly elevated ; no lateral furrows, but occipital one is present ; neck
ring a little thickened toward the middle ; fixed cheek nearly as wide as gla-
bella and gently inclined outward ; eyes fairly large, located posteriorly ; eye-
ridge weak, oblique and its front depressed ; preglabellar field one-third as
long as cranidium, gently convex and distinctly swelling up in front of gla-
bella ; anterior branches of facial sutures subparallel to each other ; posterior
ones very short and diagonal.

*Observation and comparison :—*A small cranidium is 5 mm. long and a large
one 7 mm. long.   Because the specimens are internal moulds of the tests on
sandstone, it is a question whether the eye-ridges are well impressed on the
surface of the test.   Compared to *Metagraulos dirce* (WALCOTT), 1905, this
cranidium is more inflated ; its glabella prominent and surrounded by dis-
tinct dorsal furrows.

Occurrence :—Metagraulos sampoensis zone of the Samposan formation at
locs. 314, 316 and 317.

Gênus *Megagraulos* KOBAYASHI, 1935

Megagraulos (?) *semicircularis* KOBAYASHI, new species

Plate XIII, Figures 1-4, (?) 12.

*Description :—*Cephalon semicircular, twice as long as wide, and bordered
by a thick marginal rim, ending at a short genal spine ; glabella trucate-coni-
cal, nearly as wide as fixed cheek, two-thirds as long as cranidum, strongly
convex and surrounded by profound dorsal furrow ; lateral furrows very weak
or evanescent, but occipital furrow is strong ; neck ring a little broadened
mesially ; palpebral lobes of medium size, opposed at mid-length of glabella ;
eye-band thick ; eye-ridge fairly distinct ; fixed cheek and glabella measured
through eyes nearly equal in breadth ; frontal limb convex and separated from
elevated frontal rim by a furrow ; anterior facial sutures subparallel in front
of eyes and intramarginal for some distance on marginal border.

*Observation and comparison :—*The holotype cranidium is 7 mm. long and
6.6 mm. broad.   The specimens are deformed to different degrees and tests all
dissolved.   The frontal rim is very distinct from the limb on the cranidium
in fig. 4 ; the frontal limb depressed and flattened on the cranidium in fig. 12,

but the frontal rim and limb are both convex and their separation is not so distinct on the cranidia in figs. 2 and 3.

The characteristics of this species are the very small glabella and distinct marginal rim and furrow. It is closely allied to *Megagraulos uta* (WALCOTT), but the glabella is a little larger and the eye-ridge obsolete in that species. *M. vicina* (WALCOTT) has the ridges, but the anterior outlines of the crandium as well as the glabella are more rounded and the frontal rim does not narrow near the lateral ends.

Occurrence:—*Megagraulos samposensis* zone of the Samposan or Sambangsan formation at loc. 317.

Genus *Yabeia* RESSER and ENDO, 1937

Yabeia sp. indt.

Plate XIII, Figures 14–15.

Two cranidia at hand are too badly deformed to make its specific determination, but the propriety of its reference to *Yabeia* is noted by the observations that the cranidium is subtrapezoidal, frontal margin fairly transversal, glabella truncate-conical, outlined by dorsal furrows of moderate strength, gently convex and a little elevated above cheeks, lateral furrow completely effaced, occipital furrow present, but very weak, neck ring thickened toward the middle, but not protruded into a spine, fixed cheek at eye almost as wide as glabella, small palpebral lobe located at mid-length of cranidium, eye-ridge absent and the preglabellar area simply convex and occupying no more than a third the length of cranidium; facial sutures parallel to each other or nearly so in anterior to eyes and those posterior to eyes diagonal. The surface is smooth.

Occurrence:—Green slate of Samposan formation at loc. 310.

Family Asaphiscidae RAYMOND, 1924

Genus *Anomocarella* WALCOTT, 1905

Anomocarella stenorachis KOBAYASHI, new species

Plate XIII, Figure 11.

Description:—Glabella two-thirds as long as cranidium, concial, somewhat rounded in front, strongly convex and distinctly elevated above cheeks; no lateral furrows; occipital furrow weak; neck ring narrow, but a little thickened in middle part; fixed cheek as wide as glabella on line through eyes and gently inclined laterally; eyes of moderate size, opposed at middle of glabella; eye-ridge distinct; frontal limb slightly convex and sloping forward; frontal border a little concave and depressed; facial sutures parallel to each other in front of eyes and intramarginal on border; surface smooth.

Observation:—The holotype is 9 mm. long. In this cranidium the length is equal to the breadth measured through the eyes. In the lateral view the

frontal limb and rim show a convexo-cancave curvature. The most remarkable aspects of the species are the salient glabella and large frontal limb and fixed cheeks.

Occurrence:—Metagraulos sampoensis zone of Samposan or Sambangsan formation at loc. 316.

Anomocarella cfr. *brevifrons* KOBAYASHI, 1935

Plate XII, Figure 9.

1935. cfr. *Anomocarella brevifrons* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2,* p. 297, pl. 17, figs. 10–13.
1942. *Anomocarella brevifrons* KOBAYASHI, *Proc. Imp. Acad. Tokyo, Vol. 18,* p. 305.

With such a pygidium only it is difficu´t to determine the specific identity, although it appears similar to the pygidium of *Anomocarella brevifrons*. Due to deformation this pygidium has a diagonally elongated outline. Its axial lobe which occupies two-sevenths the breadth of the pygidium, is conical, elevated a little above the slightly inflated pleural lobes, composed of more than 7 rings which are tapering slowly backward and a terminal lobe rounded at the posterior end. Pleural lobes almost smooth, but a pleural furrow is distinctly marked along the anterior margin; marginal border narrow and distinctly depressed; margin entire.

*Occurrence:—*Kan 3.

Anomocarella (?) gen. and sp. indt.

Plate XII, Figure 22.

A small pygidium probably of the Asaphiscidae is much longer than the preceding, but the proportional breadth of the axial lobe to the pygidium is not much different from that of the preceding. The lobe is abruptly narrow and pointed at the end on the posterior margin. Only an anterior pleural furrow is distinct; marginal border undeveloped.

*Occurrence:—*Kan 3.

Family Anomocaridae POULSEN, 1927

Genus *Haniwoides* KOBAYASHI, 1935

Haniwoides (?) sp. nov.

Plate XIII, Figure 16.

A strongly deformed cranidium before hand has an unfurrowed subsquare glabella, a faint occipital furrow, a neck ring of uniform thickness and a large eye-band attached to the glabella. Its preglabellar field is as long as a quarter of the cranidium and expanded forward. The frontal limb and rim appear undivided.

This preglabellar field is shorter and probably concave as in *Haniwoides longus* KOBAYASHI and *H. concavus* KOBAYASHI (1935). It is apparently not a

typical *Haniwodes,* but represents probably an undescribed species which agrees better with *Haniwoides* than *Eymekops* and other allied genera.

Occurrence :—Green slate of the Samposan formation at loc. 310.

Family Ceratopygidae LINNARSSON, 1869

Genus *Proceratopyge* WALLERIUS, 1895

Subgenus *Lopnorites* TROEDSSON, 1937

Proceratopyge (Lopnorites ?) sp. indt.

Plate XIII, Figure 18.

1920. Comp. *Asaphus* sp. YABE and HAYASAKA, *Geogr. Research in China, vol. 3*, Atlas of Fossils, pl. 16, fig. 11.
1938. Comp. *Lopnorites* sp. KOBAYASHI, *Jour. Geol. Soc. Japan, Vol. 45*, p. 323, text-fig.
1942. *Kogenium inexpectans* KOBAYASHI, *Proc. Imp. Acad. Vol. 12*, p. 105, (nom. nud.)
1956. Comp. *Proceratopyge* sp. LU, *Acta Pal. Sinica, vol. 4*, p. 282, pl. 1, fig. 7.

Though fragmentary, a pygidium from Kan 3, Mun'gyong area, is of extraordinary interest, because it reveals close resemblance with YABE and HAYASAKA's specimen from Hunan which I called *Lopnorites* sp. This Chinese specimen is composed of six thoracic segments and a part of a pygidium. The thoracic pleura is broadly falcate. The Mun'gyong pygidium is imperfect, but its pleural lobe and a part of the axis enable me to figure the general aspect of the pygidium. These two pygidia agree with each other in the high triangular outline, narrow axis, wide concave marginal border, short pleural ribs, each being divided into two riblets by an interpleural furrow and a long falcate lateral spine extended from the articulating margin.

The Hunan specimen has a sharply pointed elevation near the middle of the anterior margin of the thoracic pleura. This elevation is found also on the articulating margin of the pygidium in the Hunan specimen, but it is not seen in the Mun'gyong specimen.

This pygidium resembles *Proceratopyge (Lopnorites) rectispicatus* TROEDSSON, 1937, in the triangular outline and double ribs on the pleural lobes. In the usually broad flat median groove on the spiniferous segment and the very broad marginal border in proportion to the pleural part it is very much like *rectispicatus*. It is, however, specifically distinct, because the well developed spiniferous anterior pleural segment is bent postero-laterally, instead of posteriorly, without forming a distinct angle as seen in that species. Accordingly the outline of the pygidium of this species looks somewhat different from that of *rectispicatus*.

Among Korean trilobites this pygidium resembles *Proceratopyge (Kogenium) rotundum* and *P. (K.) triangularis*. It differs from *rotundum* in the character of the first pleural segment and other features. It is also distinct from *triangularis* in the outline of the pygidium and the aspect of the spine. It is somewhat similar to LU's *Proceratopyge* sp. from Anhwei which, however, has a broader axial lobe. Without the cephalon it is difficult to say the sub-

generic position position of the pygidium.

Occurrence:—3d division of Kanairi or Hanaeri formation at Kan 3.

Family Uncertain

Thoracic segment, gen. and sp. indt.

Plate XIII, Figure 17.

A thoracic pleura found together with the cranidia of *Yabeia* sp. and *Haniwoides* (?) sp. is straight and divided into subequal bands by a relatively thick transverse furrow. Its lateral extremity is rounded.

Occurrence:—Green slate of the Samposan formation at loc. 310. Though fragmentary, this is described because the green slate is the lowest fossiliferous horizon in the Neietsu or Yŏngwŏl type of the Cambro-Ordovician sequence and yields only a few trilobites.

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Palaeontology, VII

Cambrian Faunas of the Mun'gyong (Bunkei) District and the
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Fig. 2. Laterally compressed thorax and pygidium. ×1. 5 Kan 1.

Fig. 3. Diagonally compressed dorsal shield without free cheeks. ×1. 5 Kan 1.

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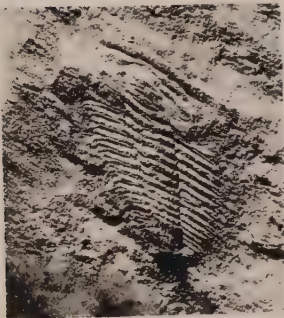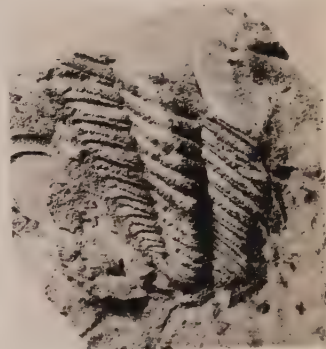
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Black slate in the lower Beiho slate formation at a point between Ichom-ni and Taehyon-ni, Soch'on-myŏn, Ponghwa-kun Kyŭngsang-bukto. (慶尚北道奉化郡小川面梨店里大幌里間)
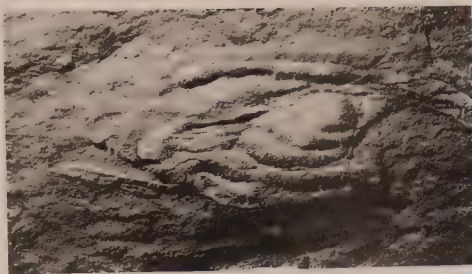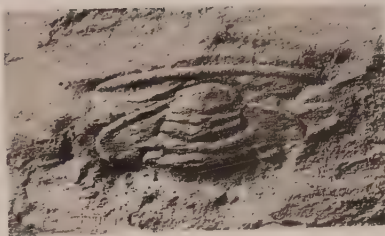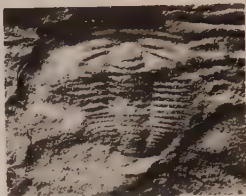
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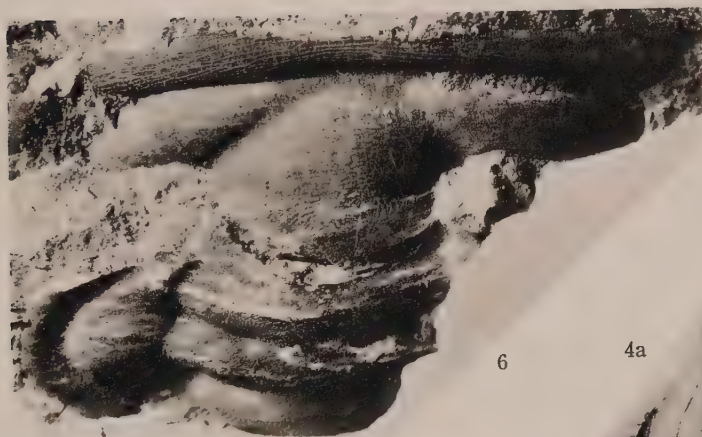
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ON THE JURASSIC PELECYPOD FAUNAS
IN JAPAN*

By

Itaru HAYAMI

(With Plate XIV)

Contents

I. General Remarks

1) Introduction

Jurassic pelecypod in Japan seem important for the stratigraphy, palaeo-ecology and palaeobiogeography, because of their abundant occurrence in various facies of many localized sedimentary áreas. Jurassic stratigraphy of this country was commenced already near the end of the last century and since then has been promoted by many authors, but few attempts had been done on the pelecypod palaeontology by the midst of this century except several works by YOKOYAMA (1904), YEHARA (1921, 1927), KOBAYASHI (1926), KOBAYASHI and SUZUKI (1937) and YABE and SATO (1942) on some trigoniids, inoceramids, cyrenoids and a few other pelecypod groups. After the war, however, KOBAYASHI, MORI and TAMURA surveyed carefully the rich Jurassic trigoniids not only in Japan but also in various areas of the Pacific region, discussing the classification and evolution. The study was lately accompli-shed with the publication of their work entitled " The bearing of the trigoniids on the Jurassic stratigraphy of Japan " in 1959. On the other hand the description of the rich pelecypod faunas of the Upper Jurassic Torinosu facies in the Soma area of northeast Japan and the Outer Zone of Southwest Japan was commenced by KIMURA (1951, 1956) and recently accomplished by TAMURA (1959a–e, 1960a–d).

Since 1954, I have engaged myself in the study on the Jurassic pelecypod faunas distributed in various areas of the Northeast Japan and the Inner Zone of Southwest Japan. Because of the unfavourable circumstances for publication, the taxonomic discussion and specific description were not com-piled in one monograph but separated into 20 papers as listed below:

1957a. Liassic *Bakevellia* in Japan. *Japan. Jour. Geol. Geogr., Vol. 28*, pp. 47–59, 2 pls.
1957b. Liassic *Gervillia* and *Isognomon* in Japan. *Ibid., Vol. 28*, pp. 95–106, 2 pls.
1957c. On the Occurrence of *Cardinioides* from the Liassic Kuruma Group in Central Japan. *Trans. Proc. Pal. Soc. Japan, N. S., No. 26*, pp. 69–73, 1 pl.
1957d. *Radulonectites*, a new pectinid genus, from the Liassic Kuruma group in Central Japan. *Ibid., N. S., No. 27*, pp. 89–93, 1 pl.
1957e. Liassic *Chlamys*, " *Camptonectes* " and other pectinids from the Kuruma group in Central Japan. *Ibid., N. S., No. 28*, pp. 119–127, 1 pl.
1958a. Liassic *Volsella*, *Mytilus* and some other dysodont species in Japan. *Ibid., N. S., No. 29*, pp. 155–165, 2 pls.
1958b. A review of the so-called Liassic " cyrenoids " in Japan. *Japan. Jour. Geol. Geogr., Vol. 29*, pp. 11–27, 2 pls.
1958c. Some Hettangian Pelecypods from the " *Trigonia*-sandstone " of the Shizukawa group in Northeast Japan. *Ibid., Vol. 29*, pp. 99–110, 1 pl.
1958d. Supplementary descriptions of the Liassic pelecypod from the Kuruma and Shizukawa groups in Japan. *Trans. Proc. Pal. Soc. N. S., No. 30*, pp. 193–200, 1 pl.
1958e. Taxonomic notes on *Cardinia* with description of a new species from the Lias of western Japan. *Jour. Fac. Sci. Univ. Tokyo, Sec. 2, Vol. 11, Pt. 2*, pp. 115–130, 1 pl.
1959a. Pelecypods of the Mizunuma Jurassic in Miyagi Prefecture, with some strati-graphical remarks. *Trans. Proc. Pal. Soc. Japan, N. S., No. 34*, pp. 66–78, 1 pl.

1959c. Bajocian pelecypods of the Aratozaki formation in Northeast Japan. *Japan. Jour. Geol. Geogr.*, *Vol. 30*, pp. 53–70, 1 pl.

1959d. Some pelecypods from the Tsukinoura formation in Miyagi Prefecture. *Trans. Proc. Pal. Soc. Japan, N.S., No. 35*, pp. 133–137.

1959e. Some pelecypods from the upper Aratozaki formation including a new genus *Kobayashites*. *Ibid., N.S., No. 35*, pp. 138–141, 1 pl.

1959f. Late Jurassic Lipodont, Taxodont and Dysodont pelecypods from Makito, Central Japan. *Japan. Jour. Geol. Geogr.*, *Vol. 30*, pp. 135–150, 1 pl.

1959g. Late Jurassic Isodont and Myacid pelecypods from Makito, Central Japan. *Ibid.*, *Vol. 30*, pp. 151–167, 1 pl.

1959i. Lower Liassic Lamellibranch fauna of the Higashinagano formation in west Japan. *Jour. Fac. Sci. Univ. Tokyo, Sec. 2, Vol. 12, Pt. 1*, pp. 31–84, 4 pls.

1960b. Pelecypods of the Jusanhama group (Purbeckian or Wealden) in Hashiura area, Northeast Japan. *Japan. Jour. Geol. Geogr.*, *Vol. 31*, pp. 13–22, 1 pl.

1960c. Jurassic Inoceramids in Japan. *Jour. Fac. Sci. Univ. Tokyo, Sec. 2, Vol. 12, Pt. 2*, pp. 277–328, 4 pls.

1960.   (with M. SUGITA and Y. NAGUMO). Pelecypods of the Upper Jurassic and Lowermost Cretaceous Shishiori group in Northeast Japan. *Japan. Jour. Geol. Geogr.*, *Vol. 31*, pp. 85–98, 1 pl.

The taxonomic descriptions in above mentioned publications have dealt with the greater part of the important representatives of the Jurassic pelecypod faunas hithero known in Japan, although several local faunules remain undescribed because of the insufficient material. More than 90 genera and more than 350 species of pelecypods can be distinguished in the Japanese Jurassic. Therefore, I dare to say that we have completed the first stage of the work.

However, little has been done as to their application to geology. Since pelecypods are the most ubiquitous fossil group in the Japanese Jurassic, it seems an essential problem for the Jurassic stratigraphy to recognize their stratigraphical and geographical distribution on the basis of the facts in local sedimentary areas. Many species of these pelecypods apparently occur in certain limited stages and geographical provinces, and they are, of course, important for intraprovincial correlation and palaeogeographical consideration. Their occurrences are, however, much dependent on facies as many other fossil groups, and attention must be paid also to their palaeoecology, especially mode of occurrence, assemblage and relationship between the bio- and litho-facies.

Here I will summerize the stratigraphical and geographical distribution of these pelecypods, and further discuss the zonation, palaeoecology and palaeobiogeography in some detail on the basis of the field observations and laboratory works. My special attention has been paid to the pelecypod faunas in the Pacific region, since Japan belongs to the circum Pacific orogenic belt and many evidences about pelecypod evolution, which may or may not agree with those in Europe, can be expected. A comprehensive catalogue of Japanese Jurassic pelecypods is added to this paper.

2) Acknowledgements

University of Tokyo, who kindly guided and encouraged me in completing the study. He gave me valuable advices and assistances from his comprehensive knowledge of geology and palaeontology since the year 1954 when I took this subject for study upon his suggestion. I am deeply indebted to Dr. Leslie R. COX of the British Museum, Prof. Tatsuro MATSUMOTO of the Kyushu University and Assist. Prof. Kôichirô ICHIKAWA of the Osaka City University for their kind advices and instructive informations about pelecypod palaeontology. I appreciate also the kindness of Prof. Fuyuji TAKAI, Assist. Prof. Toshio KIMURA, Assist. Prof. Tetsuro HANAI, Assist. Prof. Tadashi SATO and Dr. Akira TOKUYAMA of the University of Tokyo and Dr. Minoru TAMURA of the Kumamoto University who gave me various assistances and frequent opportunities for discussions in the laboratory.

3) Distribution and faunal ages

I divide tentatively the Jurassic pelecypod faunas of Japan into three suits, namely, Lower (Hettangian-Aalenian), Middle (Bajocian-Bathonian) and Upper (Callovian-Tithonian) ones. It is not only for convenience's sake but also due to their correspondence with major sedimentary cycles. These pelecypods may or may not associate with ammonites. Therefore, the faunas often cannot be dated on firm bases. The symbols*, J1a-g, J2a-c, J3a-e and J4 in Table 1, which are applied in this paper, show roughly estimated horizons on the basis of the stratigraphic sequences and associated index fossils in a few type areas.
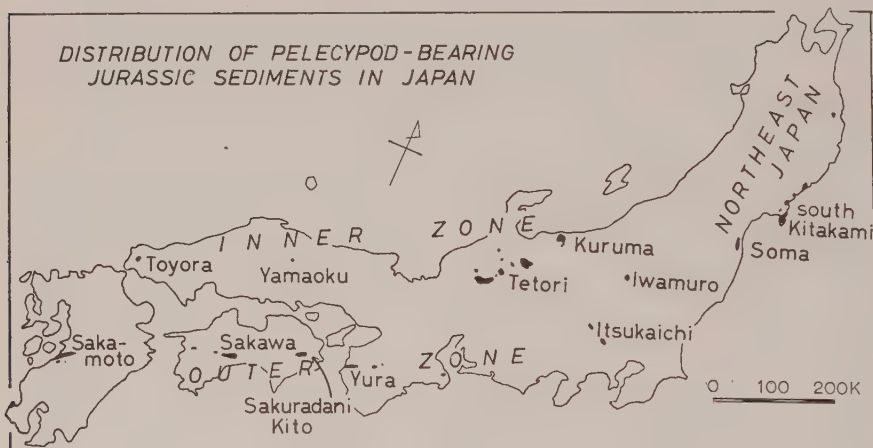
Fig. 1.

Lower Jurassic faunas are represented in the Shizukawa group in northeast Japan (Kitakami mountainland), the Kuruma group in central Japan (Hida plateau) and the Toyora group (exclusive of the main part of the Utano formation) in west Japan (Nagato region). Some pelecypods from the Yama-

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* The nomination is applied only for the indication of faunal ages instead of letter nomination for local chronological division.

oku formation of west Japan and the Iwamuro formation of the Kwanto mountainland are considered also Lower Jurassic owing to their similar aspect to the Kuruma fauna. The main localities of Lower Jurassic pelecypods which are dealt with in this study are listed below:

a. Niranohama formation of the Shizukawa, Hashiura and Mizunuma areas in Miyagi
    Prefecture.
    1. Coast of Niranohama, Utatsu town (J1a-b); 2. Hoinyashiki of Hosoura, Shizu-
    kawa town (J1b); 3. East of Hosoura, Shizukawa town (J1a); 4. Ippaishimizu
    of Hosoura, Shizukawa town (J1a); 5. North of Ippaishimizu of Hosoura, Shizu-
    kawa town (J1a-b); 6. West of Yoriki, Utatsu town (J1a); 7. Small island off
    the coast of Gongen, Shizukawa town (J1b); 8. Magenosu, Kahoku town (J1a)
    (Loc. 3, in MORI, 1949); 9. Oiwazawa, Kitakami village (J1a-b) (Loc. 4, in MORI,
    1949); 10. Yokokurazawa, Kitakami village (J1a-b) (Loc. 5, in MORI, 1949); 11.
    A tributary of Aikawazawa, Kitakami village (J1b) (Loc. 6, in MORI, 1949); 12.
    Mozasawa, Kitakami village (J1a) (Loc. 7, in MORI, 1949); 13. Tate of Onagawa,
    Kitakami village (J1a) (Loc. 8, in MORI, 1949); 14. A tributary of Aikawazawa,
    Kitakami village (J1b or J1c); 15. Middle stream of Futamataji, Mizunuma, Inai
    village* (J1a) (cf. HAYAMI, 1959h); 16. Southern slope of Mt. Kusakariyama,
    Inai village* (J1a); 17. Northern slope of Mt. Kusakariyama (J1a).
b. Hosoura formation of the Shizukawa area in Miyagi Prefecture.
    18. Small island off the coast of Gongen, Shizukawa town (J1c); 19. Bentenzaki
    of Hosoura, Shizukawa town* (J1f); 20. Jaou of Hosoura, Shizukawa town (J1g);
    21. Akaiwazaki of Hosoura, Shizukawa town (J1g).
c. Mizunuma formation of the Mizunuma area in Miyagi Prefecture.
    22. Middle stream of Kanagezawa, Mizunuma, Inai village* (?J1c).
d. Iwamuro formation of the Katashina area in Gumma Prefecture.
    23. East of the Iwamuro power plant along Katashina river, Akagine village
    (?J1e or J1f) (cf. KIMURA, 1952).
e. Tsuchizawa formation of the Kuruma area in Nagano Prefecture.
    24. Kamikawara of Kuruma, Kitaotari village (J1); 25. Upper stream of Tsuchi-
    zawa, Kuruma, Kitaotari village (J1); 26. Middle stream of Tsuchizawa, Kuruma,
    Kitaotari village (J1); 27. River cliff, south of Kuruma, Kitaotari village* (J1).
f. Kitamatadani formation of the Kurobe National Forest and Kotaki area' of Niigata
    and Toyama Prefectures.
    28. Upper stream of Kitamatadani, Kurobe National Forest* (?J1c); 29. Fukisawa-
    dani, Kurobe National Forest (?J1c); 30. Shibakurazawa of Kotaki, Itoigawa city,
    Niigata Prefecture (?J1c); 31. Lower stream of Nishimatazawa of Kotaki, Itoi-
    gawa city (?J1c); 32. Matsuozawa of Kotaki, Itoigawa city (?J1c); 33. Sakurao-
    zawa of Kotaki, Itoigawa city (?J1c); 34. Ohishi of Kotaki, Itoigawa city (?J1c);
    35. Yogurazawa of Odokoro, Itoigawa city (?J1c); 36. Middle stream of Odokoro
    river, Odokoro, Itoigawa city (?J1c).
g. Negoya formation of the Kurobe National Forest and Hashidate area in Niigata
    and Toyama Prefectures.
    37. Negoya of Daira, Kurobe National Forest* (J1d); 38. Kitadani of Daira, Kuro-
    be National Forest (J1d); 39. Mouth of Teradani, Daira, Kurobe National forest
    (J1d); 40. Kawagurodani of Daira, Kurobe National Forest (J1d); 41. Neiridani
    of Daira, Kurobe National Forest* (J1d); 42. Upper stream of Aisawadani, Hashi-
    date, Omi town, Niigata Prefecture* (J1d); 43. A tributary of Aisawadani, Hashi-
    date, Omi town (J1d).
h. Teradani formation of the Kurobe National Forest and Hashidate area in Niigata
    and Toyama Prefectures.

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* Many isolated outcrops.

44. Lower stream of Teradani, Daira, Kurobe National Forest (J1e) ; 45. Middle stream of Kanayamadani, Hashidate, Omi town, Niigata Prefecture (J1e).

i. Shinatani formation of the Kurobe National Forest and the Hashidate and Agero areas in Niigata Prefecture.

46. Upper stream of Kanayamadani, Hashidate, Omi town (J1e or J1f) ; 47. A tributary of Kanayamadani, Hashidate, Omi town (J1e or J1f) ; 48. Upper stream of Teradani, Daira, Kurobe National Forest (J1e or J1f) ; 49. Upper stream of Shinatani, Agero, Omi town (J1e or J1f).

j. Otakidani formation of the Agero area in Niigata Prefecture.

50. Middle stream of Otakidani, Agero, Omi twon (J1f). (see the geological map and fossil list in KOBAYASHI et al. (1957) about Locs. 24–50).

k. Yamaoku formation of the Osakabe area, Okayama Prefecture.

51. Primary school at Ochiai, Osakabe town (Y1 and Y2 members*) (?J1 or J1f) (cf. KONISHI, 1954).

l. Higashinagano formation of the Toyora area in Yamaguchi Prefecture.

52. West of Takayama, northeast of Higashinagano, Toyoda town* (J1b) (Locs. 1, 2, in HAYAMI, 1959i) ; 53–56. Four localities at Higashinagano, Toyoda town (J1b) (Locs. 3–6, in HAYAMI, 1959i) ; 57–59. Three localities at Higashinakayama, Kikukawa town (J1b, J1c) (Locs. 7–9, in HAYAMI, 1959i).

m. Nishinakayama formation of the Toyora area in Yamaguchi Prefecture.

60. Sakuraguchi, southwest of Ishimachi, Toyoda town (J1e) (Loc. 98, in MATSUMOTO and ONO, 1947) ; 61. Ishimachi, Toyoda town* (J1f) (Loc. 27, in MATSUMOTO and ONO, 1947).

n. Utano formation of the Toyora area in Yamaguchi Prefecture.

62. Todani, southwest of Nishinakayama, Kikukawa town* (J1g) (? Locs. 226, 230, in MATSUMOTO, and ONO, 1947).

Table 1.

HORIZONS OF MAIN JURASSIC PELECYPOD FAUNAS IN JAPAN

stage	symbol	Kitakami west	Kitakami east	Soma	Tetori Kuruma	Torinosu Toyora
Berriasian	J4	? Jusanhama	Isokusa Nagasaki		? Izuki	up. Sakamoto Kambaradani
Tithonian	J3e		up. Kogoshio	Koyamada		
	J3d		low. Kogoshio Tashiro			
Kimmeridgian	J3c		Mone	Nakanosawa	? Yambara	Kurisaka
Oxfordian	J3b				Kiritani, Mitarai Yambarazaka	Yatsuji
Callovian	J3a	up. Arato		? Yamagami	Kaizara	up. Utano
Bathonian	J2c			Awazu		? Naradani
Bajocian	J2b	low. Arato	Tsunakizaka	? Hatsuno		
	J2a	Aratozaki	Tsukinoura Kosaba			
Aalenian	J1g	up. Hosoura	? Kodaijima			low. Utano
Toarcian	J1f				Otakidani ? Shinatani Teradani	Nishinakayama
Pliensbachian	J1e					
	J1d				Negoya	
Sinemurian	J1c	low. Hosoura			? Kitamatadani	Higashinagano
Hettangian	J1b	up. Niranohama				
	J1a	low. Niranohama				

Middle Jurassic pelecypods seem comparatively poor in this country except for several small faunas distributed in the following areas of northeast

Japan.

o. Aratozaki formation of the Shizukawa, Hashiura and Mizunuma areas in Miyagi
    Prefecture.
    63. Akaiwazaki of Hosoura, Shizukawa town (J2a) ; 64. Coast of Gongen, Shizu-
    kawa town* (J2a) ; 65. Hinokuchi, Utatsu town (J2a) ; 66. West of Akaiwazaki,
    Shizuhama, Shizukawa town (J2a) ; 67. Okami, Kitakami village (J2a) (Loc. 10,
    in MORI, 1949) ; 68. Nakahara of Onagawa, Kitakami village (J2a) (Loc. 11, in
    MORI, 1949) ; 69. North of Mizunuma, Inai village* (J2a).
p. Kodaijima formation of the Ojika area in Miyagi Prefecture.
    70. Southern coast of Kodaijima, Ishinomaki city* (J1g or J2a) ; 71. Northern coast
    of Kodaijima, Ishinomaki city (J1g or J2a).
q. Tsukinoura formation of the Ojika area in Miyagi Prefecture.
    72. Kodaijima strait near Tsukinoura, Ishinomaki city (J2a) ; 73. East of Tsukino-
    ura along the Kinkazan highway, Ishinomaki city (J2a).
r. Kosaba formation of the Karakuwa area in Miyagi Prefecture.
    74. Shibitachi, Karakuwa town (J2a) ; 75. West of Tadakoshi along the Higashi-
    hama highway, Karakuwa town (J2a) ; 76. Matsubatake, Karakuwa town* (J2a).
s. Tsunakizaka formation of the Karakuwa area in Miyagi Prefecture.
    77. Southwest of Tsunakizaka-pass in Kesennuma city* (J2b) ; 78. A valley, south
    of Tsunakizaka in Kesennuma city (J2b).
t. Arato formation of the Shizukawa and Hashiura areas in Miyagi Prefecture.
    79. West of Shizuhama along the Higashihama highway, Shizukawa town (J2b) ;
    80. Kuromorisawa, Kitakami village* (? J2b, J2c or J3a) (Locs. 15, 16, in MORI,
    1949).

Besides, some inoceramid fauna from the upper part of the Utano formation
at Utano of Kikukawa village (Loc. 81) in Yamaguchi Prefecture may be
upper Middle Jurassic or lower Upper Jurassic.

Upper Jurassic pelecypods are widely distributed in the Kitakami and
Soma regions of northeast Japan, Tetori region of central Japan and Torinosu
group in the Sakuradani-Kito, Monobegawa, Sakawa, Sakamoto and some
other areas of the Outer Zone of Southwest Japan. In the Kitakami mountain-
land Upper Jurassic pelecypods occur at the following localities :

u. Mone formation of the Karakuwa area in Miyagi Prefecture.
    81. Udoura, east coast of Oshima island, Kesennuma city* (J3c).
v. Kogoshio formation of the Karakuwa area in Miyagi Prefecture.
    82. East of Shishiori along Higashihama highway, Kesennuma city (? J3e) ; 83.
    West of Yobaiji-pass, Kesennuma city (? J3e) ; 84. Wakagihama (Niranowaki),
    east coast of Oshima island, Kesennuma city (J3e) ; 85. Isokusa, west coast of
    Oshima island, Kesennuma city (J4) ; 86. Nagasaki, east coast of Oshima island,
    Kesennuma city (J4).
w. Kozumi formation (Tashiro sandstone) of the Ojika area in Miyagi Prefecture.
    87. West coast of Tashiro island, Ishinomaki city (? J3d) ; 88. West of Ayukawa,
    Ojika town (? J3d).

As to the numerous localities of Middle Jurassic pelecypods in the Soma
group and Upper Jurassic ones in the Soma, Tetori and Torinosu groups,
MASATANI (1950), MAEDA (1952a, b, 1957, etc.), KIMURA (1956) and TAMURA's
(1959a–e, 1960a–f) reports including the locality maps and lists were already
published. Since I could not add any other localities to their results, list of
localities in these groups is omitted in this paper.

List of Jurassic Pelecypods in Japan

In this list, the original specific name, author name of original description, altered specific name, author name of subsequent description, formation name (as to the complicated Torinosu group of the Sakawa basin only the zone name is listed) and horizon are treated. Generic names are arranged systematically, and the specific names alphabetically. Several undescribed pelecypods, whose generic reference is more or less clear, are also listed with asterisks.

Family Solemyacidae GRAY
    Genus *Solemya* LAMARCK, 1818
        Solemya kobayashii TAMURA, 1960d, Torinosu belt, J3a.
        Solemya suprajurensis HAYAMI, 1959f, Mitarai, J3b.
Family Ctenodontidae WOHRMANN
    Genus *Palaeoneilo* HALL, 1869
        Palaeoneilo sp., HAYAMI, 1959f, Mitarai, J3b.
Family Nuculidae GRAY
    Genus *Nuculopsis* GIRTY, 1911
      Subgenus *Palaeonucula* QUENSTEDT, 1930
        Nuculopsis (Palaeonucula) mitaraiensis HAYAMI, 1959f, Mitarai, J3b.
        Nuculopsis (Palaeonucula) sp., HAYAMI. 1959f, Mitarai, J3b.
        Nuculopsis (Palaeonucula) sp., HAYAMI, 1959i, Higashinagano, J1b.
Family *Nuculanidae* ADAMS
    Genus *Nuculana* LINK, 1807
      Subgenus *Dacryomya* AGASSIZ, 1840
        Nuculana (Dacryomya) minutula KIMURA, 1956; TAMURA, 1960d; Torinosu belt, J3a–J3e.
        Nuculana (Dacryomya) stenodolichos KIMURA, 1956; TAMURA, 1959b, 1959d, 1960d; Torinosu belt, Nakanosawa, Sakamoto, J3a–J3e.
        Nuculana (Dacryomya) toriyamae HAYAMI, 1959i, Higashinagano, J1b.
      Subgenus *Praesaccella* COX, 1940
        Nuculana (Praesaccella) yatsushiroensis TAMURA, 1959b; TAMURA, 1960d; Sakamoto, Torinosu belt, J3d–J3e.
        Nuculana (Praesaccella) sp. ex gr. *yatsushiroensis* TAMURA, HAYAMI, SUGITA and NAGUMO, 1960, Kogoshio, J3e.
        Nuculana (Rollieria ?) erinoennsis KIMURA, 1956; *Nuculana (Praesaccella) erinoensis*, TAMURA, 1959b, 1960d; Torinosu belt, Sakamoto, Miyakodani; J3a–J3e.
        Nuculana (Praesaccella) sp., HAYAMI, SUGITA and NAGUMO, 1960, Kogoshio, J3e.
        *Nuculana (Praesaccella) sp., Kiritani, J3b.
Family Parallelodontidae DALL
    Genus *Parallelodon* MEEK and WORTHEN, 1866
        Parallelodon inflatus TAMURA, 1959b, Sakamoto, J3e.
        Parallelodon aff. *inflatus* TAMURA, TAMURA, 1959d, Koyamada, J3e.
        Parallelodon infraliassicus HAYAMI, 1959i, Higashinagano, J1b.
        Parallelodon cf. *infraliassicus* HAYAMI, HAYAMI, 1959i, Higashinagano, J1b.
        Parallelodon kesennumensis HAYAMI, in HAYAMI, SUGITA and NAGUMO, 1960, Kogoshio, J3e.
        Parallelodon koikensis TAMURA, 1959d; TAMURA, 1960; Nakanosawa, Kurisaka, J3c–J3d.
        Parallelodon niranohamensis HAYAMI, 1958c; HAYAMI, 1959a; Niranohama, J1a–J1b.
        Parallelodon sp., HAYAMI, 1958d, Shinatani, J1e or J1f.
        *Parallelodon sp., Tsukinoura, J2a.
      Subgenus *Torinosucatella* TAMURA, 1959
        Catella (Torinosucatella) kobayashii TAMURA, 1959b; TAMURA, 1959d, 1960d; *Parallelodon (Torinosucatella) kobayashii*, HAYAMI, SUGITA and NAGUMO, 1960; Saka-

moto, Nakanosawa, Kurisaka, Kogoshio, J3c–J3e.

  Subgenus *Palaeocucullaea* TOKUYAMA, 1960

Parallelodon (?) *subnavicellus* HAYAMI, 1959i, Higashinagano, J1b.

Family Cucullaeidae FINLAY and MARWICK

  Genus *Grammatodon* MEEK, 1860

Grammatodon takiensis KIMURA, 1956; TAMURA, 1959b, 1959d, 1960d. HAYAMI, SUGITA and NAGUMO, 1960; Torinosu belt, Kaisekiyama belt, Kurisaka, Miyako-dani, Sakamoto, Nakanosawasa, Koyamada, Kogoshio, J3a–J3e, J4.

Grammatodon toyorensis HAYAMI, 1959i, Higashinagano, J1b.

Grammatodon sp., HAYAMI, SUGITA and NAGUMO, 1960, Kogoshio, J3e, J4.

Grammatodon (?) sp., HAYAMI, 1958d, Shinatani, J1e or J1f.

  Subgenus *Indogrammatodon* COX, 1937

Grammatodon (*Indogrammatodon*) *densestriatus* TAMURA, 1959d, Nakanosawa, J3c.

Grammatodon (*Indogrammatodon ?*) *nakanoi* HAYAMI, 1958c, Niranohahama, J1b.

  Genus *Cucullaea* LAMARCK, 1801

Cucullaea (s. l.) sp. ex gr. *aalensis* QUENSTEDT, HAYAMI, 1959c, Aratozaki, J2a.

Cucullaea (s. l.) *mabuchii* HAYAMI, 1958c, Niranohama, J1b.

Cucullaea (s. l.) sp., HAYAMI, 1959c, Aratozaki, J2a.

Family Mytilidae FLEMING

  Genus *Modiolus* LAMARCK, 1799

Volsella bakevelloides HAYAMI, 1958a; *Modiolus bakevelloides*, HAYAMI, 1958d, 1959a; Niranohama, J1a.

Modiolus cf. *bipartitus* SOWERBY, TAMURA, 1960b, Nakanosawa, J3c.

Modiolus maedae HAYAMI, 1959f, Mitarai, J3b.

Modiolus magatama HAYAMI, 1959i, Higashinagano, J1b.

Volsella sp., HAYAMI, 1958a, Shinatani, J1e or J1f.

  Subgenus *Inoperna* CONRAD, 1875

Modiolus (*Inoperna*) *plicatus* SOWERBY, TAMURA, 1960b, Nakanosawa, J3c.

Modiolus (*Inoperna*) sp., HAYAMI, 1959c, Aratozaki, J2a.

Modiolus (*Inoperna*) sp., TAMURA, 1960b, Nakanosawa, J3c.

  Genus *Mytilus* LINNÉ, 1758

  Subgenus *Falcimytilus* COX, 1937

Mytilus (*Falcimytilus*) *heranirus* HAYAMI, 1958a, Tsuchizawa, J1.

Mytilus (*Falcimytilus*) *heranirus* subsp., HAYAMI, 1958a, Kitamatadani, (?) J1c.

Mytilus (*Falcimytilus*) *stricapillatus* HAYAMI, 1958a, Shinatani, Tsuchizawa, J1e or J1f.

Mytilus (*Falcimytilus*) *stricapillatus* subsp., HAYAMI, 1958a, Negoya, J1d.

Mytilus (*Falcimytilus*) sp., HAYAMI, 1958a, Negoya, J1d.

Mytilus (*Falcimytilus*) sp., Kiritani, J3b.

  Genus *Arcomytilus* AGASSIZ, 1842

Arcomytilus dairensis KOBAYASHI and HAYAMI, in HAYAMI, 1958a, (?) Shinatani, J1e or J1f.

Brachidontes (*Arcomytilus*) *laitmairensis* (DE LORIOL); TAMURA, 1960b, 1960d, Nakanosawa, Kaisekiyama belt, J3c, J3e.

Arcomytilus sp., HAYAMI, 1958a, Shinatani, J1e or J1f.

  Genus *Brachidontes* SWAINSON, 1840

Brachidontes (?) sp., HAYAMI, 1959f, Mitarai, J3b.

Family Pteriidae MEEK

  Genus *Pteria* SCOPOLI, 1777

Pteria (s. l.) *kitakamiensis* HAYAMI, 1958a, 1959a, Niranohama, J1a.

Pteria masatanii TAMURA, 1960a, Nakanosawa, J3c.

Pteria (s. l.) sp., HAYAMI, 1959f. Mitarai, J3b.

" *Pteria* " sp., TAMURA, 1960a, Nakanosawa, J3c.

  Genus *Pteroperna* MORRIS and LYCETT, 1853

Pteroperna lingulata TAMURA, 1960a, Nakanosawa, J3c.

Pteroperna pauciradiata TAMURA, 1960a, Nakanosawa, J3c.

Pteroperna sp., TAMURA, 1959a, Sakamoto, J3e.

Pteroperna sp., TAMURA, 1960a, Nakanosawa, J3c.

Pteroperna? sp., TAMURA, 1960a, Nakanosawa, J3c.

· Genus *Somapteria* TAMURA, 1960   .

Somapteria koikensis TAMURA, 1960a, Nakanosawa, J3c.

Family Aviculopectinidae ETHERIDGE, em. NEWELL

  Subfamily Oxytominae ICHIKAWA

    Genus *Oxytoma* MEEK, 1864

      Oxytoma cf. *cygnipes* (YOUNG and BIRD) ; HAYAMI, 1959i ; Higashinagano, J1b.

      Oxytoma inequivalvis (SOWERBY) ; HAYAMI, 1959i, Higashinagano, J1b. J1c.

      Oxytoma kobayashii HAYAMI, 1959i, Higashinagano, J1c.

      Oxytoma cf. *münsteri* (GOLDFUSS) ; HAYAMI, 1959c ; Aratozaki, J2a.

      Oxytoma tetoriensis HAYAMI, 1959f, Mitarai, J3b.

      Oxytoma sp., Otakidani, J1f.

      Oxytoma sp., Y_2 member of Yamaoku, J1.

      Oxytoma (?) sp., HAYAMI, 1958a, Shinatani, J1e or J1f.

    Genus *Meleagrinella* WHITFIELD, 1885

      Meleagrinella japonica HAYAMI, 1959i, Higashinagano, J1e or J1f.

      Meleagrinella sp., Niranohama, J1b.

      Meleagrinella sp., Y_2 member of Yamaoku, J1.

Family Posidoniidae

  Genus *Posidonia* BRONN, 1828

      Posidonia sp. ex gr. *ornati* QUENSTEDT, Utano, J1g.

      Posidonia sp., Hosoura, J1g.

      Posidonia sp., Tsunakizaka, J2b.

      Posidonia sp., Kaizara, J3a.

  Genus *Amonotis* KITTL, 1904

      Amonotis n. sp., Nishinakayama, J1e.

  Genus *Aulacomyella* FURLANI, 1910

      Aulacomyella (?) sp., TAMURA, 1960a, Nakanosawa, J3c.

Family Bakevelliidae KING

  Genus *Bakevellia* KING, 1848

      Bakevellia (s. l.) *cassianelloides* KOBAYASHI and HAYAMI, in HAYAMI, 1957a, Tsuchizawa, J1.

      Bakevellia magnissima HAYAMI, 1957a, Shinatani, Iwamuro, Y_1 member of Yamaoku, J1e or J1f.

      Bakevellia negoyensis HAYAMI, 1957a, Negoya, J1d.

      Bakevellia ohishiensis HAYAMI, 1957a, Kitamatadani, (?) J1c.

      Bakevellia otariensis HAYAMI, 1957a, Tsuchizawa, J1.

      Gervillia trigona YOKOYAMA, 1904; *Bakevellia trigona*, HAYAMI, 1957a, 1959a, Niranohama, J1a–J1b.

      Bakevellia cf. *trigona* (YOKOYAMA) ; HAYAMI, 1959a, Mizunuma, (?) J1c.

      Bakevellia sp., Tsukinoura, J2a.

  Genus *Gervillia* DEFRANCE, 1820

      Gervillia takiensis TAMURA, 1960d, Torinosu belt, Kurisaka, J3a–J3d.

      Gervillia tatenosawensis TAMURA, 1960a ; TAMURA, 1960d, Nakanosawa, Kurisaka, J3c–J3d.

      Gervillia sp., HAYAMI, 1957b, Niranohama, J1a.

      Gervillia sp., HAYAMI, SUGITA and NAGUMO, 1960, Kogoshio, J3e.

    Subgenus *Cultriopsis* COSSMANN, 1904

      Gervillia (*Cultriopsis*) *shizukawensis* HAYAMI, 1957b, 1959a, Niranohama, J1a.

      Gervillia (*Cultriopsis*) sp., HAYAMI, 1957b, Tsuchizawa, J1.

  Genus *Gervillella* WAAGEN, 1907, em. COX, 1940

      Gervillella (?) sp., TAMURA, 1959a, Sakamoto, J3e.
    Genus *Kobayashites* HAYAMI, 1959
      Kobayashites hemicylindricus HAYAMI, 1959e, Aratozaki, Tsukinoura, J2a.
Family Isognomonidae DALL
    Genus *Isognomon* SOLANDER, 1786
      Perna rikuzenica YOKOYAMA, 1904 ; *Isognomon rikuzenicus,* HAYAMI, 1957b, 1959a,
        Niranohama, Hosoura, J1a–J1f.
      Isognomon cf. *rikuzenicus* (YOKOYAMA), HAYAMI, 1957b, Negoya, J1d.
     Isognomon cf. *rikuzenicus* (YOKOYAMA), Aratozaki, J2a.
      Isognomon sp., HAYAMI, 1957b, Shinatani, J1e or J1f.
      Isognomon sp., HAYAMI, 1957b, Y₁ member of Yamaoku, J1.
     Subgenus *Mytiloperna* IHRING, 1903
      Isognomon (*Mytiloperna*) *ageroensis* HAYAMI, 1957b, Shinatani, J1e or J1f.
Family Inoceramidae ZITTEL
    Genus *Parainoceramus* VORONETZ, 1936
      Parainoceramus lunaris HAYAMI, 1960c, Nishinakayama, J1e.
      Parainoceramus matsumotoi HAYAMI, 1960c, Nishinakayama, J1f.
      Parainoceramus cf. *matsumotoi* HAYAMI, HAYAMI, 1960c, Nishinakayama, J1f.
      Parainoceramus sp. ex gr. *matsumotoi* HAYAMI, HAYAMI, 1960c, Nishinakayama,
        J1f.
      Inoceramus (s. l.) sp., HAYAMI, 1959c ; *Parainoceramus* sp., HAYAMI, 1960c ; Arato-
        zaki, J2a.
    Genus *Inoceramus* SOWERBY, 1814
      Inoceramus (s. l.) *fukadae* HAYAMI, 1960c, Kodaijima, J1g or J2a.
      Inoceramus furukawensis HAYAMI, 1960c, Sugizaki, J3b.
      Inoceramus sp. ex gr. *fuscus* QUENSTEDT, HAYAMI, 1960c, Utano, J1g.
      Inoceramus sp. ex gr. *galoi* BOEHM, HAYAMI, 1960c, Arato, somewhere from J2b
        to J3d.
      Inoceramus hamadae HAYAMI, 1960c, Kaizara, J3a.
      Inoceramus hashiurensis HAYAMI, 1960c, Arato, somewhere from J2b to J3d.
      Inoceramus (s. l.) *kudoi* HAYAMI, 1960c, Hosoura, J1g.
      Inoceramus cf. *lucifer* VON EICHWALD, HAYAMI, 1960c, Tsunakizaka, J2b.
      Inoceramus maedae HAYAMI, 1960c, Mitarai, J3b.
      Inoceramus maedae HAYAMI, var., HAYAMI, 1960c, Mitarai, J3b.
      Inoceramus maedae HAYAMI, var., HAYAMI, 1960c, Mitarai, J3b.
      Inoceramus morii HAYAMI, 1959c ; HAYAMI, 1960c ; Aratozaki, Kosaba, J2a.
      Inoceramus (?) *naganoensis* HAYAMI, 1960c, Nagano, J3b.
      Inoceramus cf. *nitescens* ARKELL, HAYAMI, 1960c, Nagano, J3b.
      Inoceramus ogurai KOBAYASHI, 1926 ; HAYAMI, 1960c ; Utano, J2c or J3a.
      Inoceramus utanoensis KOBAYASHI, 1926 ; HAYAMI, 1960c ; Utano, J2c or J3a.
      Inoceramus (s. l.) sp., HAYAMI, 1960c, Kodaijima, J1g or J2a.
      Inoceramus (s. l.) sp., HAYAMI, 1960c, Tsunakizaka, J2b.
      Inoceramus (s. l.) sp., HAYAMI, 1960c, Mitarai, J3b.
     Inoceramus (s. l.) sp., Tsukinoura, J2a.
     Inoceramus sp., Shimohambara, (?) J2b.
     Subgenus *Mytiloceramus* ROLLIER, 1914
      Inoceramus (*Mytiloceramus*) *karakuwensis* HAYAMI, 1960c, Tsunakizaka, J2b.
Family Pinnidae GRAY
    Genus *Pinna* LINNÉ, 1758
      Pinna cf. *mitis* PHILLIPS, TAMURA, 1960b, Nakanosawa, J3c.
      Pinna sp. ex gr. *sandsfootensis* ARKELL, HAYAMI, 1959f, Mitarai, J3b.
      Pinna sp., TAMURA, 1960d, Kaisekiyama belt, J3.
      Pinna sp., HAYAMI, SUGITA and NAGUMO, 1960, Kogoshio, J3e.
     Pinna sp., Kiritani, J3b.
Family Plicatulidae IREDALE

Genus *Plicatula* LAMARCK, 1801

    Plicatula dichotomocosta TAMURA, 1959d, Nakanosawa, J3c.

    Plicatula aff. *dichotomocosta* TAMURA, TAMURA, 1960d, Kaisekiyama belt, J3.

    Plicatula praenipponica HAYAMI, 1959i, Higashinagano, J1b.

    Plicatula subcircularis HAYAMI, 1959i, Higashinagano, J1b.

    Plicatula yatsujiensis TAMURA, 1960d, Torinosu belt, Kaisekiyama belt, Miyako-dani, J3a, J3.

    *Plicatula sp., Shinatani, J1e or J1f.

    *Plicatula sp., Niranohama, J1b.

Family Pectinidae LAMARCK

Genus *Chlamys* RÖDING, 1798

    Chlamys camptonectoides TAMURA, 1959d, Nakanosawa, J3c.

    Chlamys iboibo KURATA and KIMURA, in KIMURA, 1951; TAMURA, 1959b, 1960d, Kaisekiyama belt, Mitoda belt, Sakamoto, J3a J3e.

    Chlamys kobayashii HAYAMI, 1959d, Tsukinoura, Kosaba, J2a.

    Chlamys kotakiensis TAKAI and HAYAMI, in HAYAMI, 1957e, Kitamatadani, (?) J1c.

    Chlamys kurumensis KOBAYASHI and HAYAMI, in HAYAMI, 1957e, Tsuchizawa, J1.

    Chlamys cf. *kurumensis* KOBAYASHI and HAYAMI, HAYAMI, 1957e, Tsuchziawa, J1.

    Chlamys mitaraiensis HAYAMI, 1959g, Mitarai, J3b.

    Chlamys textoria (SCHLOTHEIM); HAYAMI, 1959i, Higashinagano, J1b.

    Chlamys sp., HAYAMI, 1957e, Tsuchizawa, J1.

    Chlamys sp., TAMURA, 1959d, Nakanosawa, J3c.

    Chlamys (*Chlamys*) sp., TAMURA, 1959b, Sakamoto, J3e.

    *Chlamys sp., Yamagami, (?) J3a.

Genus "*Aequipecten*" FISCHER, 1887

    Neithea kotsubu KIMURA, 1951; "*Aequipecten*" *kotsubu*, TAMURA, 1959b, 1959d, 1960d; Kaisekiyama belt Torinosu belt, Kurisaka, Sakamoto, Nakanosawa, J3a–J3e.

    "*Aequipecten*" *toyorensis* HAYAMI, 1959i, Higashinagano, J1b.

    Aequipecten vulgaris KIMURA, 1951; "*Aequipecten*" *vulgaris*, TAMURA, 1959b, 1959d, 1960d; Torinosu belt, Kaisekiyama belt, Kurisaka, Miyakodani, Nakanosawa, Sakamoto, J3a–J3e.

    "*Aequipecten*" sp., HAYAMI, 1959i, Higashinagano, J1b.

Genus *Radulopecten* ROLLIER, 1911

    Chlamys nagatakensis KURATA and KIMURA, in KIMURA, 1951; *Chlamys* (*Radulopecten*) *nagatakensis*, TAMURA, 1959b, 1960d; Mitoda belt, Sakamoto, J3, J3e.

    Aequipecten ogawensis KIMURA, 1951; *Chlamys* (*Radulopecten*) *ogawensis*, TAMURA, 1959b, 1959d, 1960d; Torinosu belt, Shiraishigo, Sakamoto, Nakanosawa, J3a–J3e.

Genus *Camptonectes* MEEK, 1864

    Camptonectes cf. *auritus* (SCHLOTHEIM), HAYAMI, 1959c, Aratozaki, J2a.

    Camptonectes aff. *browni* COX, TAMURA, 1959b, Sakamoto, J3e.

    Camptonectes inexpectatus HAYAMI, 1959a, Niranohama, J1a.

    Camptonectes (?) *mimikirensis* KURATA and KIMURA, in KIMURA, 1951; TAMURA, 1960d, Kaisekiyama belt, J3.

    "*Camptonectes*" *oishii* KOBAYASHI and HAYAMI, in HAYAMI, 1957e, Tsuchizawa, Kitamatadani, J1, (?) J1c.

    "*Camptonectes*" *subflabelliformis* HAYAMI, 1957e, Kitamatadani, (?) J1c.

    Camptonectes torinosuensis KURATA and KIMURA, in KIMURA, 1951; TAMURA, 1960d; Kaisekiyama belt, Kurisaka, J3, J3c.

    Camptonectes sp., TAMURA, 1960d, Torinosu belt, (?) J3d.

    Camptonectes sp., TAMURA, 1959d, Nakanosawa, J3c.

    Camptonectes sp., HAYAMI, 1959g, Mitarai, J3b.

    *Camptonectes sp., Niranohama, J1b.

    "*Camptonectes*" sp., HAYAMI, 1957e, Kitamatadani, (?) J1c.

"*Camptonectes*" sp., HAYAMI, 1957e, Shinatani, J1e or J1f.

Genus *Radulonectites* HAYRMI, 1957

Radulonectites japonicus HAYAMI, 1957d, Tsuchizawa, J1.

Radulonectites japonicus HAYAMI, var. *convexus*, HAYAMI, 1957d, Tsuchizawa, J1.

Genus *Eopecten* DOUVILLÉ, 1897

Eopecten kurisakensis TAMURA, 1960d, Kurisaka, J3c.

Velata puncta KIMURA, 1951; *Eopecten punctus*, TAMURA, 1959d, 1960d; Kaiseki-yama belt, Nakanosawa, J3c, J3.

Eopecten n. sp., TAMURA, 1959b, Sakamoto, J3e.

Eopecten (?) sp., HAYAMI, 1957e, Iwamuro, J1.

Family Amusiidae RIDEWOOD

Genus *Entolium* MEEK, 1865

Entolium cf. *calvum* (GOLDFUSS); HAYAMI, 1959i, Higashinagano, J1b, (?) J1c.

Entolium cf. *disciforme* (SCHÜBLER); HAYAMI, 1959c, Aratozaki, Kodaijima, (?) J1g, J2a.

Entolium inequivalve HAYAMI, 1959g, Mitarai, J3b.

Entolium japonicum KURATA and KIMURA, in KIMURA, 1951; TAMURA, 1960d, Kaisekiyama belt, J3.

Entolium kimurai TAMURA, 1959b; TAMURA, 1959d, 1960d; HAYAMI, SUGITA and NAGUMO, 1960; Sakamoto, Koyamada, Kurisaka, Torinosu belt, Kaisekiyama belt, Kogoshio, J3a–J3e.

Entolium cf. *lunare* (ROEMER); HAYAMI, 1959i, Higashinagano, J1b.

Entolium yatsujiense KURATA and KIMURA, in KIMURA, 1951; TAMURA, 1959b, 1959d, 1960d, Torinosu belt, Go, Nagayasu, Miyakodani, Sakamoto, Nakanosawa, J3a–J3e.

Entolium sp., HAYAMI, 1957e, Tsuchizawa, J1 (=*Entolium* cf. *calvum* (GOLDFUSS) in HAYAMI, 1959i).

Entolium sp., HAYAMI, 1959i, Higashinagano, J1c.

Entolium (?) sp., HAYAMI, 1959i, Higashinagano, J1b.

Genus *Somapecten* KIMURA, 1951

Somapecten kamimanensis KIMURA, 1951; TAMURA, 1959b, 1959d, 1960d, Nakano-sawa, Torinosu belt, Kaisekiyama belt, Kurisaka, Miyakodani, Sakamoto, J3a–J3e.

Genus *Variamussium* SACCO, 1897

Propeamussium habunokawensis KIMURA, 1951; *Variamussium habunokawense*, TAMURA, 1959b, 1960d; Torinosu belt, Miyakodani, Sakamoto, J3a–J3e.

Variamussium cf. *habunokawense* (KIMURA); HAYAMI, SUGITA and NAGUMO, 1960, Kogoshio, J4.

Variamussium sp., Hosoura, J1c.

Variamussium (?) sp., HAYAMI, 1957e, Teradani, J1e.

Family Limidae D'ORBIGNY

Genus *Lima* BRUGUIÈRE, 1957

"*Lima*" sp., HAYAMI, 1959i, Higashinagano, J1c.

Genus *Plagiostoma* SOWERBY, 1814

Lima (*Plagiostoma*) *enormicosta* TAMURA, 1959d; TAMURA, 1960d; Nakanosawa, Kaisekiyama belt, J3c.

Plagiostoma kobayashii HAYAMI, 1959i, Higashinagano, J1b.

Plagiostoma matsumotoi HAYAMI, 1959i, Higashinagano, J1b, (?) J1c.

Plagiostoma sp. ex gr. *subcardiiforme* (GREPPIN), Yamagami, (?) J3a.

Plagiostoma sp., HAYAMI, 1959i, Higashinagano, J1c.

Lima (*Plagiostoma*) sp., TAMURA, 1959b, Sakamoto, J3e.

Lima (*Plagiostoma*) sp., TAMURA, 1959d, Nakanosawa, J3c.

Plagiostoma sp., Tsukinoura, J2a.

Genus *Antiquilima* COX, 1943

Antiquilima nagatoensis Hayami, 1959i, Higashinagano, J1b.

Genus *Ctenoides* Mörch, 1853

Lima (Ctenoides) tosana Kurata and Kimura, in Kimura, 1951; Tamura, 1959b, 1960d; Kaisekiyama belt, Mitoda belt, Torinosu belt, Kurisaka, Miyakodani, Sakamoto, (?) J3a, J3c–J3e.

Genus *Limatula* Wood, 1839

Limatula akiyamae Hayami, in Hayami, Sugita and Nagumo, 1960, Kogoshio, J4.

Limatula iwayae Hayami, 1959g, Mitarai, J3b.

Limatula reticulata Tamura, 1959b, Sakamoto, J3e.

Genus *Ctenostreon* von Eichwald, 1862

Ctenostreon japonicum Hayami, 1959i, Higashinagano, J1b.

Ctenostreon ojikense Hayami, 1959d, Tsukinoura, J2a.

Ctenostreon proboscideum (Sowerby); Tamura, 1959d, Nakanosawa, J3c.

Ctenostreon sp. ex gr. *proboscideum* (Sowerby), Hayami, 1959c, Aratozaki, J2a.

Ctenostreon sp., Hayami, 1959i, Higashinagano, J1b.

Family Ostreidae Lamarck

Genus *Liostrea* Douvillé, 1904

Liostrea toyorensis Hayami, 1959i, Higashinagano, J1b.

Liostrea sp., Tamura, 1959b, Sakamoto, J3e.

Subgenus *Catinula* Rollier, 1911

Liostrea (Catinula) cf. *stoliczkai* Cox, Tamura, 1960d, Kaisekiyama belt, Kurisaka, J3, J3c.

Genus *Ostrea* Linné, 1758

"*Ostrea*" sp., Hayami, 1958a, Shinatani, J1e or J1f.

"*Ostrea*" sp., Hayami, 1958a, Tsuchizawa, J1.

*"*Ostrea*" sp., Niranohama, J1a.

*"*Ostrea*" sp., Ushimaru, (?) J3a.

Genus *Exogyra* Say, 1819

Exogyra kumensis Tamura, 1959a; Tamura, 1960c, 1960d; Sakamoto, Nakanosawa, Kurisaka, Miyakodani, Kaisekiyama belt, J3c–J3e.

Genus *Lopha* Röding, 1798

Lopha cf. *eruca* (Defrance); Tamura, 1960d, Kaisekiyama belt, Kurisaka, J3, J3c.

Lopha gregarea (Sowerby); Tamura, 1960d, Kaisekiyama belt, J3.

Lopha cf. *marshii* (Sowerby), Tamura, 1960d, Kaisekiyama belt, Torinosu belt, Kurisaka

Lopha sazanami Hayami, 1959i, Higashinagano, J1b.

Lopha sp., Niranohama, J1a.

Lopha sp., Hayami, 1959d, Tsukinoura, J2a.

Lopha sp., Hayami, 1959d, Tsukinoura, J2a.

Lopha sp., Kogoshio, J3e.

Family Trigoniidae Lamarck

Subfamily Trigoniinae Kobayashi

Genus *Trigonia* Bruguière, 1789

Trigonia senex Kobayashi and Mori, 1954, Niranohama, J1b.

Trigonia sumiyagura Kobayashi and Kaseno, 1947; Kobayashi and Mori, 1954; Hayami, 1959c; Aratozaki, Kosaba, J2a.

Trigonia sumiyagura Kobayashi and Kaseno, var., Kobayashi and Mori, 1954, Kodaijima, J1g or J2a.

Genus *Geratrigonia* Kobayashi, 1954

Trigonia hosourensis Yokoyama, 1904; *Geratrigonia hosourensis*, Kobayashi and Mori, 1954; Hayami, 1959a; Niranohama, J1a, (?) J1b.

Geratrigonia hosourensis (Yokoyama) var. *convexa* Kobayashi, in Kobayashi and Mori, 1954, Niranohama, J1a.

Geratrigonia lata KOBAYASHI, in KOBAYASHI and MORI, 1954, Niranohama, J1a–J1b.

Geratrigonia kurumensis KOBAYASHI, 1957a, Otakidani, J1f.

Genus *Latitrigonia* KOBAYASHI, 1957

Latitrigonia orbicularis KOBAYASHI, 1957a, Yambarazaka, J3b.

Latitrigonia pyramidalis KOBAYASHI and TAMURA, 1957, Awazu, J2c.

Latitrigonia tetoriensis KOBAYASHI, 1957a, Yambarazaka, J3b.

Latitrigonia unicarinata KOBAYASHI and TAMURA, 1957, Yamagami, (?) J3a.

Latitrigonia unituberculata KOBAYASHI and TAMURA, 1957, Yamagami, (?) J3a.

Genus *Ibotrigonia* KOBAYASHI, 1957

Ibotrigonia masatanii KOBAYASHI and TAMURA, 1957, Awazu, Yamagami, J2c, (?) J3a.

Ibotrigonia masatanii KOBAYASHI and TAMURA, var., KOBAYASHI and TAMURA, 1957, Yamagami, (?) J3a.

Genus *Nipponitrigonia* COX, 1952

Trigonia sagawai YEHARA, 1926; *Nipponitrigonia sagawai*, KOBAYASHI, 1957c; TAMURA, 1960d; Kaisekiyama, belt, Torinosu belt, Awazu, Yamagami, Nakanosawa, Kiritani, (?) Sugizaki, J2c–J3e.

Subfamily Prosogyrotrigoniinae KOBAYASHI

Genus *Prosogyrotrigonia* KRUMBECK, 1924

Trigonia inouyei YEHARA, 1921; YEHARA, 1931; *Prosogyrotrigonia inouyei*, KOBAYASHI and MORI, 1954; Higashinagano, J1b.

Subfamily Vaugoniinae KOBAYASHI

Genus *Vaugonia* CRICKMAY, 1930

Vaugonia awazuensis KOBAYASHI in KOBAYASHI and TAMURA, 1957, Awazu, J2c.

Vaugonia kodaijimensis KOBAYASHI and MORI, 1955, Kodaijima, Tsukinoura, (?) Aratozaki, J1g–J2a.

Vaugonia namigashira KOBAYASHI and MORI, 1955, Niranohama, J1b.

Vaugonia niranohamensis KOBAYASHI and MORI, 1955, Niranohama, Hosoura, Aratozaki, J1b–J2a.

Vaugonia yambarensis KOBAYASHI, 1956, Yambara, J3.

Vaugonia yokoyamai KOBAYASHI and MORI, 1955, Niranohama, Aratozaki, Tsukinoura, J1b–J2a. (=*Trigonia v-costata* YOKOYAMA, 1904, non LYCETT, 1872)

Vaugonia yokoyamai forma *gracilis* KOBAYASHI and MORI, 1955, Niranohama, J1b.

Subgenus *Hijitrigonia* KOBAYASHI, 1955

Vaugonia (Hijitrigonia) geniculata KOBAYASHI and MORI, 1955; HAYAMI, 1959c, Aratozaki, Kosaba, J2a.

Vaugonia (Hijitrigonia) kojiwa KOBAYASHI and MORI, 1955, Niranohama, J1b.

Genus *Orthotrigonia* COX, 1952

Orthotrigonia corrugata KOBAYASHI and MORI, 1955, Niranohama, J1b.

Orthotrigonia midareta KOBAYASHI and MORI, 1955, Niranohama, J1b.

Genus *Scaphotrigonia* COX, 1952

Scaphotrigonia somensis KOBAYASHI and TAMURA, 1957, Yamagami, (?) J3a.

Subfamily Myophorellinae KOBAYASHI

Genus *Myophorella* BAYLE, 1878

Myophorella (Myophorella) dekaiboda KOBAYASHI and TAMURA, 1955, Nakanosawa, J3c.

Subgenus *Promyophorella* KOBAYASHI and TAMURA, 1955

Myophorella (Promyophorella?) hashimotoi KOBAYASHI, 1956; TAMURA, 1960d, Kurisaka, J3c.

Myophorella (Promyophorella) imamurai KOBAYASHI, 1956, Kiritani, J3b.

Myophorella (Promyophorella) obsoleta KOBAYASHI and TAMURA, 1955; KOBAYASHI, 1956; HAYAMI, SUGITA and NAGUMO, 1960; Kogoshio, Hommura, (?) Arimine, J3e–J4.

      Myophorella (*Promyophorella*) *orientalis* KOBAYASHI and TAMURA, 1955; KO-
           BAYASHI, 1957a, 1957b; Koyamada, Tashiro, Kogoshio, Yambarazaka, J3b–J3e.
      Myophorella (*Promyophorella*) *sigmoidalis* KOBAYASHI and TAMURA, 1955; HAYA-
           MI, 1959c; Aratozaki, J2a.
      Myophorella (*Promyophorella*) *sugayensis* KOBAYASHI and TAMURA, 1955, Yama-
           gami, (?) J3a.
      Myophorella (*Promyophorella*) *sugayensis* var. *geniculata* KOBAYASHI and TA-
           MURA, 1955, Yamagami, (?) J3a.
      Myophorella (*Promyophorella*) sp., TAMURA, 1959a, Sakamoto, J3e.
      Myophorella (*Promyophorella*) sp., TAMURA, 1959a, Sakamoto, J3e.
    Subgenus *Haidaia* CRICKMAY, 1930, em. KOBAYASHI and TAMURA, 1955
      Myophorella (*Haidaia*) *crenulata* KOBAYASHI and TAMURA, 1955; KOBAYASHI,
           1957b; Nakanosawa, Mone, J3c.
      Myophorella (*Haidaia*) *crenulata* var. *lunulata* KOBAYASHI and TAMURA, 1955,
           Nakanosawa, J3c.
      Myophorella (*Haidaia*) *gracilenta* KOBAYASHI, 1956; TAMURA, 1959a, 1960d;
           Kaisekiyama belt, Mitoda belt, Sakamoto, J3a–J3e.
      Myophorella (*Haidaia*) *ohmachii* TAMURA, 1959a, Sakamoto, J3e.
      Myophorella (*Haidaia*) *pulex* TAMURA, 1959a; TAMURA, 1960d; Sakamoto, Tori-
           nosu belt, Mitoda belt, Kaisekiyama belt, Kurisaka, J3a–J3e.
      Myophorella (*Haidaia*) *subcircularis* KOBAYASHI and TAMURA, 1955, Nakanosawa,
           J3c.
      Myophorella (*Haidaia*) sp., KOBAYASHI, 1956, Kappazaka, (?) J3c.
    Genus *Linotrigonia* VAN HOEPEN, 1929
      Trigonia toyamai YEHARA, 1923; YEHARA, 1927, 1931; *Linotrigonia toyamai*, KO-
           BAYASHI, 1956d; TAMURA, 1960d; Torinosu belt, Kaisekiyama, belt, Kurisaka,
           Miyakodani, J3a–J3c.
    Genus *Oistotrigonia* COX, 1952
      Oistotrigonia prima KOBAYASHI and TAMURA, 1955, Nakanosawa, J3c.
Family Unionidae FLEMING
    "Genus *Unio* RETZIUS, 1788"
      Unio ogamigoensis KOBAYASHI and SUZUKI, 1937, Ogamigo, J3 or later.
Family Pachicardiidae
    Genus *Cardinioides* KOBAYASHI aud ICHIKAWA, 1952
      Cardinioides ovatus HAYAMI, 1957c, Kitamatadani, (?) J1c.
      Cardinioides varidus HAYAMI, 1957c, Tsuchizawa, J1.
      Cardinioides (?) sp., HAYAMI, 1957c, Iwamuro, J1.
Family Cardiniidae ZITTEL
    Genus *Cardinia* AGASSIZ, 1841
      Cardinia orientalis HAYAMI, 1959i, Higashinagano, J1b.
      Cardinia toriyamai HAYAMI, 1958e; HAYAMI, 1959i; Higashinagano, J1b.
Family Myoconchidae
    Genus *Myoconcha* SOWERBY, 1824
      Myoconcha (?) sp., TAMURA, 1960b, Nakanosawa, J3c.
Family Astartidae GRAY
    Genus *Astarte* SOWERBY, 1817
      Astarte defecta TAMURA, 1959a; TAMURA, 1960c, 1960d; Sakamoto, Nakanosawa,
           Mitoda belt, Kaisekiyama belt, (?) Kurisaka, J3c–J3e.
      Astarte (?) sp. aff. *hermanni* OPPEL, TAMURA, 1959a, Sakamoto, J3e.
      Astarte higoensis TAMURA, 1959a; TAMURA, 1960d; Sakamoto, (?) Torinosu belt,
           J3e, (?) J3a.
      Astarte kambarensis KIMURA, 1956; TAMURA, 1960c, 1960d; Torinosu Nakanosawa,
           Koyamada, J3c–J3e.
      Astarte kambarensis var. *elongata* KIMURA, 1956, Torinosu belt, J3e.

Astarte ogawensis KIMURA, 1956; TAMURA, 1959a, 1960c, 1960d; Torinosu belt, Sakamoto, Nakanosawa, J3a–J3e.

Astarte cf. *spitiensis* STOLICZKA, HAYAMI, SUGITA and NAGUMO, 1960, Kogoshio, J3e–J4.

Astarte subdepressa BLAKE and HUDLESTON, TAMURA, 1960c, Nakanosawa, Koyamada, J3c–J3e.

Astarte sp., HAYAMI, 1959i, Higashinagano, J1b.

Astarte sp., HAYAMI, 1959i, Higashinagano, J1b.

Astarte n. sp., HAYAMI, SUGITA and NAGUMO, 1960, Kogoshio, J4.

Astarte (?) sp., HAYAMI, SUGITA and NAGUMO, 1960, Kogoshio, J3e.

Genus *Coelastarte* BOEHM, 1893

Coelastarte cardiniiformis HAYAMI, 1958c, Niranohama, J1b.

Coelastarte sp. ex gr. *cardiniiformis* HAYAMI, HAYAMI, 1959c, Aratozaki, J2a.

Astarte (*Coelastarte*) *somensis* TAMURA, 1960c, Nakanosawa, J3c.

Coelastarte sp., HAYAMI, 1959i, Aratozaki, J2a.

Coelastarte sp., HAYAMI, SUGITA and NAGUMO, 1960, Kogoshio, J3e.

Coelastarte sp., Kiritani, J3b.

Genus *Praeconia* STOLICZKA, 1871

Praeconia cf. *tetragona* (TERQUEM), HAYAMI, 1959i, Higashinagano, J1b.

Genus *Opis* DEFRANCE, 1825

Subgenus *Trigonopis* MUNIER-CHALMAS, 1887

Opis (*Trigonopis*) n. sp. aff. *corallina* DAMON, ICHIKAWA, 1954, Osako, J3.

Opis (*Trigonopis*) *torinosuensis* KIMURA, 1956; TAMURA, 1959c, 1960c, 1960d; Torinosu belt, Kaisekiyama belt, Nagayasu, Sakamoto, Nakanosawa, J3a–J3e.

Opis (*Trigonopis*) *trigonalis* TAMURA, 1959c, Sakamoto, J3e.

Subgenus *Coelopis* MUNIER-CHALMAS, 1887

Opis (*Coelopis*) *tanourensis* TAMURA, 1959c, Sakamoto, J3e.

Opis (*Coelopis* ?) sp., TAMURA, 1960c, Nakanosawa, J3c.

Family Neomiodontidae CASEY

Genus *Eomiodon* COX, 1935

Eomiodon (?) *giganteus* HAYAMI, 1958b, Niranohama, J1a, (?) J1b.

Eomiodon kumamotoensis TAMURA, 1959c; TAMURA, 1960d; Sakamoto, Miyakodani, J3, J3e.

Cyrena lunulata YOKOYAMA, 1904; *Polymesoda lunulata*, SUZUKI and OYAMA, 1943; *Eomiodon lunulatus*, HAYAMI, 1958b, 1959b, Niranohama, J1a, (?) J1b.

Eomiodon vulgaris HAYAMI, 1958b, Kitamatadani, Negoya, Shinatani, (?) Otakidani, Tsuchizawa, Niranohama, Tsukinoura, Iwamuro, Y_1 member of Yamaoku, J1a–J2a.

Eomiodon sp., HAYAMI, 1958b, Kitamatadani, (?) J1c.

Eomiodon (?) sp., HAYAMI, 1958b, Tsuchizawa, J1.

Eomiodon sp., Aratozaki, J2a.

Genus *Crenotrapezium* HAYAMI, 1958

Crenotrapezium kitakamiense HAYAMI, 1960b, Jusanhama, (?) J4.

Crenotrapezium kurigata HAYAMI, 1958b, Kitamatadani, Tsuchizawa, (?) J1c, J1.

Crenotrapezium kurumense HAYAMI, 1958b, Kitamatadani, Negoya, Shinatani, Tsuchizawa, Y_1 member of Yamaoku, (?) Iwamuro, J1c–J1f.

?Genus *Neomiodon* FISCHER, 1887

Corbicula amagashiraensis KOBAYASHI and SUZUKI, 1937, Amagashiradani, (?) J3.

Corbicula tetoriensis KOBAYASHI and SUZUKI, 1937; *Corbicula* (*Mesocorbicula*) *tetoriensis*, SUZUKI and OYAMA, 1943; Izuki, Numamachi, Ushimaru, Ogamigo, J3.

Family Corbiculidae GRAY

Genus *Batissa* GRAY, 1852

Batissa antiqua KOBAYASHI and SUZUKI, 1937, Izuki, Numamachi, J3.

Batissa yokoyamai KOBAYASHI and SUZUKI, 1937, Izuki, Ushimaru, Numamachi, J3.

Genus *Filosina* CASEY, 1955
 Filosina jusanhamensis HAYAMI, 1960b, Jusanhama, J4 (?).
Family Arcticidae NICOL
 Genus *Anisocardia* MUNIER-CHALMAS, 1863
  Anisocardia sp., TAMURA, 1959c, Sakamoto, J3e.
 Genus *Isocyprina* ROEDER, 1882
  Isocyprina shizuhamensis HAYAMI, 1959c. Aratozaki, J2a.
 Genus *Arctica* SCHUMACHER, 1817
  Subgenus *Somarctica* TAMURA, 1960
   Arctica (Somarctica) abukumensis TAMURA, 1960c, Nakanosawa, J3c.
 Genus *Eocallista* DOUVILLÉ, 1912
  "*Eocallista*" *regularis* TAMURA, 1959c, Sakamoto, J3e.
 Genus *Yokoyamaina* HAYAMI, 1958
  Cyrena elliptica YOKOYAMA, 1904 ; *Polymesoda elliptica*, SUZUKI and OYAMA, 1943 ;
   Yokoyamaina elliptica, HAYAMI, 1958b, 1959a ; Niranohama, J1a.
  Yokoyamaina cf. *elliptica* (YOKOYAMA), HAYAMI, 1958b, Negoya, J1d.
  Yokoyamaina (?) sp., HAYAMI, 1958b, Tsuchizawa, J1.
Family Lucinidae
 Genus *Lucina* LAMARCK, 1799
  Lucina (s. l.) *hasei* HAYAMI, 1959i, Higashinagano, J1b.
  "*Lucina*" *toishiyamensis* TAMURA, 1960d, Torinosu belt, (?) J3d.
  Lucina tsunoensis KIMURA, 1956b ; TAMURA, 1959c, 1960d ; Torinosu belt, Kaiseki-
   yama belt, Sakamoto, J3a–J3e.
Family Fimbriidae NICOL
 Genus *Fimbria* MEGERLE, 1811
  Fimbria (?) *tenuiconcha* HAYAMI, 1959c, Aratozaki, J2a.
  Fimbria sp., HAYAMI, 1959i, Higashinagano, J1b.
 Genus *Sphaeriola* STOLICZKA, 1871
  Sphaeriola nipponica HAYAMI, 1959i, Higashinagano, J1b.
Family Tancrediidae FISCHER
 Genus *Tancredia* LYCETT, 1850
  Tancredia rostrata TAMURA, 1959c, Sakamoto, J3e.
  Tancredia sp., Kiritani, J3b.
Family Cardiidae LAMARCK
 Genus *Cardium* LINNÉ, 1758
  Cardium (s. l.) *naganoense* HAYAMI, 1959i, Higashinagano, J1b.
 Genus *Protocardia* BEYRICH, 1845
  Protocardia inaii HAYAMI, 1959e, Aratozaki, J2a.
  Protocardia kurumensis HAYAMI, 1958d, Shinatani, Tsuchizawa, J1e or J1f.
  Protocardia morii HAYAMI, 1960b, Jusanhama, J4 (?).
  Protocardia onoi HAYAMI, 1959i, Higashinagano, J1b.
  Protocardia tosensis KIMURA, 1956b ; TAMURA, 1959a, 1960c, 1960d ; Torinosu belt,
   Kurisaka, Sakamoto, Nakanosawa, Koyamada, J3a–J3e.
  Protocardia sp., HAYAMI, 1959g, Mitarai, J3b.
  Protocardia sp., Kiritani, J3b.
  Protocardia sp., Kogoshio, J3e.
Family Corbulidae FLEMING
 Genus *Corbula* BRUGUIÈRE, 1797
  Corbula globosa TAMURA, 1959c ; TAMURA, 1960c, 1960d ; Sakamoto, Nakanosawa,
   Koyamada, Mitoda belt, Torinosu belt, Kurisaka, J3c–J3e.
  Corbula (?) sp., HAYAMI, 1960b, Jusanhama, J4 (?).
Family Pholadidae LEACH
 Genus *Myopholas* DOUVILLÉ, 1907
  Myopholas cf. *acuticostata* (SOWERBY), TAMURA, 1960b, Nakanosawa, J3c.
Family Pleuromyacidae ZITTEL

Genus *Pleuromya* AGASSIZ, 1843

    Pleuromya hashidatensis HAYAMI, 1958d, Teradani, J1e.

    Pleuromya hidensis HAYAMI, 1959g, Mitarai, J3b.

    Pleuromya (?) *punctostriae* TAMURA, 1959c; TAMURA, 1960b; *Pleuromya punct-ostriae*, TAMURA, 1960d; Sakamoto, Nakanosawa, Torinosu belt, J3a–J3e.

    Pleuromya sp., HAYAMI, SUGITA and NAGUMO, 1960, Kogoshio, J3e–J4.

    Pleuromya sp., HAYAMI, 1959i, Higashinagano, J1b.

Family Pholadomyacidae GRAY

  Genus *Pholadomya* SOWERBY, 1823

    Pholadomya (?) *ashikitensis* TAMURA, 1959c, Sakamoto, J3e.

    Pholadomya somensis TAMURA, 1960b, Nakanosawa, J3c.

    Pholadomya cf. *somensis* TAMURA, TAMURA, 1960d, Kurisaka, J3c.

    Pholadomya sp., HAYAMI, 1959c, Aratozaki, J2a.

  Genus *Tetorimya* HAYAMI, 1959

    Tetorimya carinata HAYAMI, 1959g, Mitarai, J3b.

  Genus *Neoburmesia* YABE and SATO, 1942

    Neoburmesia iwakiensis YABE and SATO, 1942; TAMURA, 1960b, Nakanosawa, J3c.

  Genus *Goniomya* AGASSIZ, 1843

    Goniomya nonvscripta TAMURA, 1960b, Nakanosawa, J3c.

    Goniomya cf. *nonvscripta* TAMURA, TAMURA, 1960d, Kurisaka, J3c.

    Goniomya sp., TAMURA, 1959c, Sakamoto, J3e (=*Goniomya nonvscripta* TAMURA).

  Genus *Homomya* AGASSIZ, 1843

    Homomya gibbosa (SOWERBY); TAMURA, 1960b, Nakanosawa, J3c.

    Homomya satoi HAYAMI, 1958d, Shinatani, J1e or J1f.

    Homomya sp., HAYAMI, 1958d, Kuruma group (exact horizon unknown).

  Genus *Arcomya* AGASSIZ, 1843

    Arcomya (?) sp., TAMURA, 1959c, Sakamoto, J3e.

Family Burmesiidae HEALEY

  Genus *Burmesia* HEALEY, 1908

    Burmesia japonica HAYAMI, 1959a, Niranohama, J1a.

Family Thraciidae DALL

  Genus *Thracia* BLAINVILLE, 1824

    Thracia fukushimensis TAMURA, 1960c, Nakanosawa, J3c.

    Thracia shokawensis HAYAMI, 1959g, Mitarai, J3b.

    *Thracia cf. *shokawensis* HAYAMI, Kiritani, J3b.

    Thracia subrhombica HAYAMI, 1958d; HAYAMI, 1959a; Niranohama, J1a.

    Thracia (?) sp., HAYAMI, 1958d, Shinatani, J1e or J1f.

Family Cuspidariidae FISHER

  Genus *Cuspidaria* NARDO, 1840

    Cuspidaria (?) *praenipponica* HAYAMI, 1959a, Niranohama, J1a.

    Cuspidaria (?) sp., HAYAMI, 1958d, Niranohama, J1a. (=*Cuspidaria* (?) *praenipponica* HAYAMI).

    Cuspidaria (?) sp., HAYAMI, 1958d, Shinatani, J1e or J1f.

    Cuspidaria (?) sp., HAYAMI, 1960b, Jusanhama, J4 (?).

Besides, there are some Jurassic pelecypods, which were listed but remain undescribed, from the Sodenohama, Mone, Kogoshio and Kozumi formations of south Kitakami (SHIIDA, 1940; MATSUMOTO, 1953; ONUKI, 1956, etc.), the Sugizaki and Arimine formations of Hida (MAEDA, 1957; MAEDA and TAKE-NAMI, 1957, etc.) and the Torinosu group and its correlatives in Kyushu, Shikoku and Kii peninsula (ICHIKAWA, 1954; TAMURA, 1960e). As I have not yet examined those collections, they are mostly omitted in this list.

Table 2. Number of pelecypods in the Jurassic of Japan

Family	Kitakami	Hida	Nagato	Soma	Torinosu	Total
Solemyacidae	0	1	0	0	1	2
Ctenodontidae	0	1	0	0	0	1
Nuculidae	0	2	1	0	0	3
Nuculanidae	2	1	1	1	4	8
Parallelodontidae	4	1	3	3	3	11
Cucullaeidae	6	1	1	2	1	9
Mytilidae	2	11	1	4	1	18
Pteriidae	1	1	0	7	1	10
Aviculopectinidae	2	5	4	0	0	11
Posidoniidae	2	1	2	1	0	6
Bakevelliidae	7	6	0	1	2	16
Isognomonidae	2	4	0	0	0	6
Inoceramidae	11	9	7	0	0	27
Pinnidae	1	2	0	1	1	5
Plicatulidae	1	1	2	1	2	7
Pectinidae	4	13	3	7	13	37
Amusiidae	3	3	4	3	5	15
Limidae	4	1	7	4	4	18
Ostreidae	5	3	2	1	6	16
Trigoniidae	19	8	1	17	11	47
Unionidae	0	1	0	0	0	1
Pachicardiidae	0	3	0	0	0	3
Cardiniidae	0	0	2	0	0	2
Myoconchidae	0	0	0	1	0	1
Astartidae	7	1	3	7	11	25
Neomiodontidae	5	7	0	0	1	12
Corbiculidae	1	2	0	0	0	3
Arcticidae	2	2	0	1	2	7
Lucinidae	0	0	1	0	2	3
Fimbriidae	1	0	2	0	0	3
Tancrediidae	0	1	0	0	1	2
Cardiidae	3	3	2	1	1	9
Corbulidae	1	0	0	1	1	2
Pholadiidae	0	0	0	1	0	1
Pleuromyacidae	1	2	1	1	1	5
Pholadomyacidae	1	3	0	4	5	13
Burmesiidae	1	0	0	0	0	1
Thraciidae	1	3	0	1	0	5
Cuspidariidae	2	1	0	0	0	3
Total	102	104	50	71	80	374

II. Faunules and Zonation

Among various groups of Jurassic fossils ammonites are, of course, of primary importance for the age determination and international correlation. The specific range of pelecypods is generally much longer than ammonites': life range of a single pelecypod species is often as long as a third or even a half of Jurassic period in which many ammonite zones are involved. Their value as keen time-indicator for interprovincial correlation and palaeogeographical consideration is therefore much inferior to ammonites. However, pelecypods have some advantages for intraprovincial correlation among isopic or even heteropic strata, because of their explosive development and common occurrence in various rock types. They seem generally to have been able to adapt to wider environment than ammonites. Incidentally, the occurrence of Jurassic ammonites of this country is almost restricted to arenaceous shales and sandstones of more or less off-shore facies. On the other hand, pelecypods are common in sandstones of various grain-size, sandy shales, black shales, marls, limestones and even in conglomerate.

Since 1955 I have visited most of the Jurassic pelecypod localities so far known in the North Japan and the Inner Zone of Southwest Japan, which were listed in the preceding chapter and attempted to recognize the specific assemblage in each fossil bed. Especially in the Kitakami and Hida mountainlands where similar facies appear repeatedly at many horizons of the stratigraphic columns, the determination of life range of each pelecypod species is indispensable for the biostratigraphical consideration in ammonite-lacking strata.

If one intends to carry out a biostratigraphical subdivision of Jurassic strata by means of pelecypods which is comparable in accuracy with that by ammonite genera, it must be dependent on the specific or infra-specific assemblages. Moreover, the subdivision must be based chiefly on the experince in each local sedimentary area instead of the introduction of faunal successions in foreign type areas. The faunal successions in the Jurassic of Japan are more or less discontinuous, and many fossil groups may be disqualified for chronology, because of their colonial habits and considerable dependence on facies. Taking care for these points, I tried to determine provisionally the range of each pelecypod species and to distinguish many characteristic faunules which seem useful intraprovincial correlation. Among Kitakami, Hida and Toyora regions there are only a few common species. This fact indicates the distribution of faunules to be confined to each palaeobiogeographical province, where the following zonations are independently established (Table 3).

1) Kitakami region

In the Kitakami mountainland, Hettangian, Sinemurian, Aalenian, Bajocian, Tithonian and Berriasian pelecypod faunules are well represented, but Pliensbachian deposit is unknown and Bathonian to Kimmeridgian species

Table 3.

CHARACTERISTIC PELECYPOD FAUNULES IN NORTHEAST JAPAN AND INNER ZONE OF SOUTHWEST JAPAN

region / stage		NORTHEAST JAPAN Kitakami	Shizukawa	Hashiura	Mizunuma	Karakuwa	Ojika	CENTRAL JAPAN Hida	WEST JAPAN Nagato
LOW. NEOCOMIAN	J4	("Polymesoda" naumanni f.) (Filosina jusanhamensis f.) Myophorella obsoleta f.	×		×		×	("Corbicula" tetoriensis f.)	
TITHONIAN	J3e	Parallelodon kesennumensis f. Myophorella orientalis f.			× ×	×			
	J3d								
KIMMERIDGIAN	J3c	Myophorella crenulata f.			×			(Entolium inequivalve f.) (Tetorimya carinata f.) (Inoceramus maedae f.) (Nipponitrigonia sagawai f.) Latitrigonia tetoriensis f. Inoceramus cf. nitescens f.	
OXFORDIAN	J3b								
CALLOVIAN	J3a	(Inoceramus hashiurensis f.)	?	×				Inoceramus hamadae f.	(Inoceramus utanoensis f.)
BATHONIAN	J2c								
BAJOCIAN	J2b	Inoceramus karakuwensis f. Chlamys kobayashii f.				× ×	× ×		
	J2a	Kobayashites hemicylindricus f. Trigonia sumiyagura f. (Vaugonia kodaijimensis f.)	× × ?	×	×	× ×	× × ×		
AALENIAN	J1g	Inoceramus kudoi f.	×					Geratrigonia kurumensis f.	Inoceramus sp. ex gr. fuscus f. Posidonia sp. ex gr. ornati f.
TOARCIAN	J1f							Bakevellia magnissima f. Camptonectes sp. f Pleuromya hashidatensis f.	Parainoceramus matsumotoi f. Parainoceramus lunaris f
PLIENSBACHIAN	J1e							Bakevellia negoyensis f.	
	J1d								
SINEMURIAN	J1c	Variamussium sp. f. Meleagrinella sp. f.	× ×	×				Bakevellia ohishiensis f. (Chlamys kurumensis f.) (Radulonectites japonicus f.)	Oxytoma kobayashii f. Prosogyrotrigonia inouyei f.
	J1b	Trigonia senex f.	×	×					Cardinia toriyamai f.
HETTANGIAN	J1a	Geratrigonia hosourensis f. Burmesia japonica f.	× ×	×	× ×				

seem quite rare. Pelecypods occur most commonly in coastal and embayment deposits, and the scarceness of pelecypods except for inoceramids and posidoniids in the monotonous Arato formation and similar strata is possibly due to the too off-shore environment.

(1) *Burmesia japonica* faunule (J1a, Locs. 1, 15)

This faunule is found in the black bituminous shales of the lowermost part of the Niranohama formation (lower Hettangian or ? Rhaetic) at Shizu-kawa and Mizunuma areas, and composed of the following species: *Burmesia japonica* Hayami*, *Modiolus bakevelloides* (Hayami), *Bakevellia trigona* (Yokoyama), *Eomiodon vulgaris* Hayami, *Thracia subrhombica* Hayami and *Cuspidaria* (?) *praenipponica* Hayami. The genus *Burmesia*, established by Healey (1908) from the Napeng beds of Upper Burma, has been reported from the Noric-Rhaetic of Southeastern Asia. But the associated pelecypods in the Kitakami region are commonly found also in the superjacent *Geratrigonia hosourensis* beds, and the age must not be much older than the latter faunule.

(2) *Geratrigonia hosourensis* (J1a, Locs. 1, 3, 4, 5, 6, 8, 9, 10, 12, 13, 15, 16, 17)

The characteristic assemblage of this faunule is commonly found in the black bituminous shales and sandstones of the lower Niranohama formation (lower-middle Hettangian) in Shizukawa, Hashiura and Mizunuma areas, where *Geratrigonia hosourensis* (Yokoyama)* forms striking fossil banks altogether

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* Characteristic species of the faunule.

with the following species: *Parallelodon niranohamensis* HAYAMI, *Modiolus bakevelloides* (HAYAMI), *Pteria* (s. l.) *kitakamiensis* HAYAMI*, *Bakevellia trigona* (YOKOYAMA), *Gervillia* (*Cultriopsis*) *shizukawensis* HAYAMI*, *Isognomon rikuzenicus* (YOKOYAMA), *Camptonectes inexpectatus* HAYAMI*, *Eomiodon lunulatus* (YOKO-YAMA)*, *E. vulgaris* HAYAMI, *Eomiodon* (?) *giganteus* HAYAMI*, *Yokoyamaina elliptica* (YOKOYAMA)*, *Thracia subrhombica* HAYAMI and *Cuspidaria* (?) *praenipponica* HAYAMI. *Modiolus*, *Thracia* and *Cuspidaria* (?) are especially common in the shaly part.

(3) *Trigonia senex* faunule (J1b, Locs. 1, 2, 5, 9, 10, 11)

This faunule is seen in the strikingly crowded trigoniid banks of the upper Niranohama formation (middle-upper Hettangian) in the Shizukawa area. *Trigonia senex* KOBAYASHI* occurs in common with *Parallelodon niranohamensis* HAYAMI, *Grammatodon* (*Indogrammatodon*?) *nakanoi* HAYAMI*, *Cucullaea* (s. l.) *mabuchii* HAYAMI*, *Bakevellia trigona* (YOKOYAMA), *Isognomon rikuzenicus* (YOKOYAMA), *Vaugonia niranohamensis* KOBAYASHI and MORI, *V. yokoyamai* KOBAYASHI and MORI, *V. namigashira* KOBAYASHI and MORI*, *V.* (*Hijitrigonia*) *kojiwa* KOBAYASHI and MORI*, *Geratrigonia lata* KOBAYASHI, *Orthotrigonia midareta* KOBAYASHI and MORI*, *O. corrugata* KOBAYASHI and MORI*, *Coelastarte cardiniiformis* HAYAMI*, *Yebisites onoderai* MATSUMOTO* and *Latomeandra yabei* EGUCHI*. Some species of this faunule are also common in the similar trigoniid banks of the upper Niranohama formation of the Hashiura area.

(4) *Meleagrinella* sp. faunule (J1b, Locs. 7, 14)

This is an undescribed faunule but very characteristic of the uppermost part of the Niranohama formation in Shizukawa and Hashiura areas. *Meleagrinella* sp.*, *Camptonectes* sp. and some other minute pelecypods forms a thin crowded fossil bed. (upper Hettangian or lower Sinemurian).

(5) *Variamussium* sp. faunule (J1c, Loc. 18)

This is also undescribed but seem to characterize the poor faunule of the lowermost Hosoura formation (Hi in SATO, 1957, lower Sinemurian) in the Shizukawa area. *Vaugonia ninanohamensis* is found in association.

(6) *Inoceramus* (s. l.) *kudoi* faunule (J1g, Locs. 20, 21)

This faunule including *Inoceramus* (s. l.) *kudoi* HAYAMI*, *Pinna* sp.* and *Posidonia* sp. occurs in the Aalenian *Hammatoceras* beds (SATO, 1954) of the Hosoura formation in the Shizukawa area. Associate ammonites are *Hammatoceras chibai*, *H. hosourense*, *H. subtile*, *H. tuberculatum*, *H. kitakamiense*, *Tmetoceras recticostatum*, *Hyperlioceras* sp. and *Graphoceras* spp.

(7) *Vaugonia kodaijimensis* faunule (J1g or J2a, Loc. 70)

This faunule comprising *Vaugonia kodaijimensis* KOBAYASHI and MORI*, *Entolium* cf. *disciforme* (SCHÜBLER) and some other undescribed pelecypods is found in several fossil banks of the Kodaijima formation in the Ojika area. The age is not determinable in detail but presumably Aalenian or lower Bajocian. *Inoceramus fukakae* HAYAMI* was found nearby. A few specimens of *V. kodaijimensis* are known from the lower part of the Aratozaki formation in the Shizukawa area.

(8) *Trigonia sumiyagura* faunule (J2a, Locs. 63, 64, 65, 67, 68, 69, 71, 74, 75)

This is one of the most widely distributed and characteristic faunule in the Kitakami Jurassic. It is found in the lower part of the Aratozaki formation (lower Bajocian) in Shizukawa and the lower part the Kosaba formation (probably same age) in the Karakuwa. In the Shizukawa area *Trigonia sumiyagura* KOBAYASHI and KASENO* occurs in common with *Cucullaea* sp. ex gr. *aalensis* QUENSTEDT*, *Modiolus* (*Inoperna*) sp.*, *Oxytoma* cf. *münsteri* BRONN*, *Inoceramus morii* HAYAMI*, *Parainoceramus* (?) sp., *Camptonectes* cf. *auritus* (SCHLOTHEIM)*, *Entolium* cf. *disciforme* (SCHÜBLER), *Ctenostreon* sp. ex gr. *proboscideum* (SOWERBY)*, *Vaugonia niranohamensis* KOBAYASHI and MORI, *V.* (*Hijitrigonia*) *geniculata* KOBAYASHI and MORI*, *Myophorella* (*Promyophorella*) *sigmoidalis* KOBAYASHI and TAMURA*, *Coelastarte* sp. ex gr. *cardiniiformis* HAYAMI*, *Coelastarte* sp., *Isocyprina shizuhamensis* HAYAMI*, *Fimbria* (?) *tenuiconcha* HAYAMI*, a soninid (?) ammonite, "*Rhynchonella*" sp. and *Isastraea* sp. It is of special interest that this faunule comprises several forms which are, if not identical with, very similar to foreign famous Middle Jurassic pelecypods. In the Kosaba formation this faunule is represented by *Trigonia sumiyagura,* *Vaugonia* (*Hijitrigonia*) *geniculata, Inoceramus morii, Lopha* sp. and *Fimbria* (?) *tenuiconcha.* In Hashiura area *Trigonia sumiyagura* has not been found, but the "Nakahara sandstone", which is certainly an equivalent of the Aratozaki, yields *Vaugonia niranohamensis* and *V. yokoyamai.* *Vaugonia* (*Hijitrigonia*) cf. *geniculata* and *Myophorella* (*Promyophorella*) cf. *sigmoidalis* are collected also from the comparable formation in Mizunuma area. A varietal form of *Trigonia sumiyagura* was described from the upper part of the Kodaijima formation in the Ojika area. This faunule appears at the beginning of the Middle Jurassic sedimentary cycle in the Kitakami region and stratigraphically important.

(9) *Kobayashites hemicylindricus* faunule (J2a, Locs. 66, 72, 73)

This is found characteristically in the black bituminous slales of the upper Aratozaki formation (lower Bajocian) of the Shizukawa area and the Tsukinoura formation (probably Bajocian) of the Ojika area. *Kobayashites hemicylindricus* HAYAMI*, is accompanied by *Isognomon* sp. ex gr. *rikuzenicus* (YOKOYAMA), *Protocardia inaii* HAYAMI*, and *Eomiodon* (?) sp. in the upper Aratozaki and by *Parallelodon* sp., *Bakevellia* sp. and *Eomiodon vulgaris* HAYAMI in the Tsukinoura.

(10) *Chlamys kobayashii* faunule (J2a, Locs. 72, 74)

This is characteristic in the trigoniid-sandstone of the Tsukinoura formation (probably Bajocian) in Ojika. It is almost coeval with the preceding faunule but appears in different facies. The constituent species are *Chlamys kobayashii* HAYAMI*, *Ctenostreon ojikense* HAYAMI*, *Lopha* spp. and *Vaugonia yokoyamai* KOBAYASHI and MORI. *Chlamys kobayashii* is found also in the upper part of the Kosaba formation of the Karakuwa area and the middle part of the Tsukinoura formation of the Takenoura area, and seems important in the Jurassic stratigraphy of the eastern belt.

(11) *Inoceramus karakuwensis* faunule (J2b, Locs. 75, 76)

Inoceramus (*Mytiloceramus*) *karakuwensis* HAYAMI*, *I.* cf. *lucifer* VON EICHWALD* and *Posidonia* sp. are known in the ammonite beds of the Tsuna-

kizaka formation (middle Bajocian) of the Karakuwa area. *Stephanoceras* sp. ex gr. *plicatissimum* and some other ammonite occur near this horizon. *Inoceramus lucifer* has been treated as a Bajocian index in Alaska, and distributed also in Prince Patrick and Sichota Alin (?) regions. Its coexistence with *Stephanoceras* is highly probable.

(12) *Inoceramus hashiurensis* faunule (J2b–J3c, Loc. 80, etc.)

Inoceramus hashiurensis HAYAMI* and *I.* sp. ex gr. *galoi* BOEHM* are known in the middle (?) part of the Arato formation of Hashiura. *Inoceramus galoi* is an index of Oxfordian age in Moluccas and New Zealand, but the exact age of this faunule is indeterminable.

(13) *Myophorella crenulata* faunule (J3c, Loc. 81)

This undescribed faunule is characteristic in the upper part of the Mone alternation formation of the Karakuwa area. *Myophorella* (*Haidaia*) *crenulata* KOBAYASHI and TAMURA* associates with *Myophorella* (*Promyophorella*) sp. and *Nuculana* sp. (Pl. XIV, Fig. 8). The age is not strictly determinable but the occurrence of *crenulata* suggest that this faunule is roughly correlative to that of the "*Lima*-sandstone" of the lower Nakanosawa formation (Kimmeridgian) in the Soma area. Incidentally, *Haidaia* is unknown from other horizons in the south Kitakami region.

(14) *Myophorella orientalis* faunule (? J3d–J3e, Loc. 87)

Myophorella (*Promyophorella*) *orientalis* KOBAYASHI and TAMURA* occurs in the Tashiro sandstone (upper Kozumi formation) of the Ojika area and (?) the Kogoshio formation of the Karakuwa area. The species is distributed widely in Soma, Kitakami and Tetori regions and also in Mindoro island, and ranges from Oxfordian to Tithonian (or Berriasian).

(15) *Parallelodon kesennumensis* faunule (J3e, Loc. 84)

Parallelodon kesennumensis HAYAMI*, *Gervillia* sp.*, *Entolium kimurai* TAMURA, *Coelastarte* sp., *Pleuromya* sp., *Parallelodon* (*Torinosucatella*) *kobayashii* TAMURA, *Substeuveroceras* sp.* and *Trochocyathus* (*Platycyathus*) sp.* are found in the upper part of the Kogoshio formation of Karakuwa.

(16) *Myophorella obsoleta* faunule (J3e–J4, Locs. 82, 83, 85, 86)

This faunule is found in the upper part of the Kogoshio formation and Isokusa and Nagasaki blocks in the Karakuwa area, and Tithonian-Berriasian in age. The ranges of the present and preceding faunules seem to overlap each other, but the two are fairly different in specific assemblage. *Myophorella* (*Promyophorella*) *obsoleta* KOBAYASHI and TAMURA* associates with *Nuculana* (*Praeasccella*) sp. ex gr. *yatsushiroensis* TAMURA, *Grammatodon takiensis* KIMURA, *Variamussium* cf. *habunokawense* (KIMURA), *Pinna* sp., *Limatula akiyamae* HAYAMI*, *Astarte* cf. *spitiensis* STOLICZKA*, *Protocardia* sp. and *Pleuromya* sp. Some of these pelecypods are accompanied by *Thurmanniceras isokusense*, *Kilianella* sp. and an echinoid at Isokusa and by *Olcostephanus* sp., *Berriasella* sp. and *Spiticeras* sp. at Nagasaki. This faunule thus comprises some elements of the Torinosu and upper Soma groups. Many forms are identical or comparable with the species from the Nakanosawa and Koyamada formations of Soma and the Kurisaka, Yatsuji, Kambaradani and Sakamoto formations of

the Outer Zone of Southwest Japan.

(17) *Filosina jusanhamensis* faunule (? J4, Loc. 89)

Filosina jusanhamensis HAYAMI* forms a striking fossil bank altogether with *Crenotrapezium kitakamiense* HAYAMI*, *Protocardia morii* HAYAMI*, *Corbula* (?) sp. and *Cuspidaria* (?) sp. in the middle part of the Jusanhama group (Purbeckian or Wealden) of the Hashiura area. This is a unique faunule, and its exact age and distribution outside this bed is as yet unknown.

(18) " *Polymesoda* " *naumanni* faunule

" *Polymesoda* " *naumanni* NEUMAYR*, *Bakavellia* cf. *shinanoensis* (YABE and NAGAO) and some other cyrenoid pelecypods occur in the Ayukawa formation of the Ojika area (ONUKI, 1956). The first species is well known in the Wealden Ryoseki group of the Katsuragawa, Ryoseki and Sanchu Graben regions, and indicates the Lower Cretaceous age of the Ayukawa formation.

2) Hida region

In the Hida mountainland Lower Jurassic pelecypods are well represented in the Kuruma group and Upper Jurassic ones in the Tetori group. But Middle Jurassic faunas seem poor. In this region ammonites and pelecypods occur usually in different facies. Generally, this region constituted a more or less restricted province at that time, and cosmopolitan pelecypod elements are very rare. The following faunules are composed of several characteristic species, though their exact ages are not always confirmed.

(1) *Radulonectites japonicus* faunule (J1, Locs. 25, 26, 27)

This faunule is found in the black shales and sandstones of the Tsuchizawa formation of the Kuruma area. The age is indeterminable but must be somewhere in Lias. The constituent pelecypods are *Radulonectites japonicus* HAYAMI*, *R. japonicus* var. *convexus* HAYAMI*, *Mytilus (Falcimytilus) heranirus* HAYAMI*, *M. (F.)⁻ stricapillatus* HAYAMI, *Bakevellia otariensis* HAYAMI*, *Bakevellia* (s. l.) *cassianelloides* KOBAYASHI and HAYAMI*, *Isognomon* sp., " *Camptonectes* " *oishii* KOBAYASHI and HAYAMI, *Cardinioides varidus* HAYAMI*, *Crenotrapezium kurumense* HAYAMI, *C. kurigata* HAYAMI, *Eomiodon vulgaris* HAYAMI and *E.* (?) sp.

(2) *Chlamys kurumensis* faunule (J1, Loc. 24)

Chlamys kurumensis KOBAYASHI and HAYAMI* coexists with *Chlamys* sp., *Entolium* cf. *calvum* (GOLDFUSS) and *Gervillia (Cultriopsis?)* sp. in the medium sandstone of the Tsuchizawa formation at Kamikawara of the Kuruma area. The pectinids are somewhat similar to those in the lower Liassic Higashinagano formation of the Nagato region.

(3) *Bakevellia ohishiensis* faunule (? J1c, Locs. 28, 29, 30, 33, 34, 36)

This faunule is characteristic of the Kitamatadani formation (probably lower Lias) in the Inugatake area, comprising the following species: *Bakevellia ohishiensis* HAYAMI*, *Mytilus (Falcimytilns) heranirus* HAYAMI subsp.*, *Chlamys kotakiensis* TAKAI and HAYAMI*, " *Camptonectes* " *oishii* KOBAYASHI and HAYAMI, " *C.* " *subflabelliformis* HAYAMI*, " *C.* " sp., *Cardinoides ovatus* HAYAMI*, *Crenotrapezium kurumense* HAYAMI, *C. kurigata* HAYAMI, *Eomiodon vulgaris*

HAYAMI and *E.* sp.*

(4) *Bakevellia negoyensis* faunule (J1d, Locs. 37, 38, 40, 41, 42, 43)

Bakevellia negoyensis HAYAMI* is characteristic in the Negoya formation (lower ? Pliensbachian) of the Inugatake area and associates with *Mytilus stricapillatus* HAYAMI subsp.*, *Isognomon* sp., *Crenotrapezium kurumense* HAYA-MI, *Eomiodon vulgaris* and *Yokoyamaina* sp.

(5) *Pleuromya hashidatensis* faunule (J1e, Locs. 44, 45)

Pleuromya hashidatensis HAYAMI* and *Variamussium* (?) sp.* occur in the marine sandy shales of the Teradani formation (upper Pliensbachian) of the Inugatake area. *Amaltheus* sp. and *Canavaria* sp. ex gr. *geyeriana* associated with them. But the most part of the Kuruma group is represented by much different facies and the exact range of this pelecypod faunule cannot be determined.

(6) "*Camptonectes*" sp. faunule (J1e or J1f, Loc. 46)

"*Camptonectes*" sp.* and *Oxytoma* sp. occur in the lower part of the Shinatani formation of the Inugatake area (upper Pliensbachian or Toarcian). It is also a unique facies in the Kuruma group.

(7) *Bakevellia magnissima* faunule (J1e or J1f, Locs. 47, 48, 49, 51, 23)

This is an important faunule in the embayment facies of the Inner Zone, distributed not only in the Kuruma group but also in the Iwamuro and Yamaoku formations respectively in Gumma and Okayama Prefectures. In the Inugatake area *Bakevellia magnissima* HAYAMI* occurs in the black sand-stones and shales of the middle-upper part of the Shinatani formation (upper Pliensbachian-Toarcian) in common with *Parallelodon* sp., *Grammatodon* (?) sp., *Modiolus* sp., *Arcomytilus* sp., *Mytilus* (*Falcimytilus*) *stricapillatus* HAYAMI, *Isognomon* (*Mytiloperna*) *ageroensis* HAYAMI*, *Isognomon* sp., *Ostrea* sp., *Creno-trapezium kurumense* HAYAMI, *Eomiodon vulgaris* HAYAMI, *Protocardia kurum-ensis* HAYAMI*, *Homomya satoi* HAYAMI*, *Thracia* sp., *Cuspidaria* (?) sp. and *Pseudotrapezium* sp. *Bakevellia magnissima* is accompanied by *Eopecten* (?) sp., *Cardinioides* (?) sp., *Crenotrapezium kurumense* and *Eomiodon vulgaris* in the lower-middle part of the Iwamuro formation and by *Isognomon* sp., *Crenotrape-zium kurumense* n. subsp., *Eomiodon vulgaris*, etc. in the Y_1 member of the Yamaoku formation. There is no good evidence of the upper Liassic age for these two fossil beds, but they are provisionally correlated to the Shinatani formation in view of the similar aspect of pelecypod assemblage.

(8) *Meleagrinella* sp. faunle (J1, probably J1e or J1f, Loc. 51)

Meleagrinella sp., *Oxytoma* sp. and *Nuculana* (*Dacryomya*) sp. constitute a small faunule in the Y_2 member of the Yamaoku formation.

(9) *Geratrigonia kurumensis* faunule (J1f, Loc. 50)

Geratrigonia kurumensis KOBAYASHI* and *Oxytoma* sp., though rarely, occur in the marine sandy shales of the Otakidani formation of the Inugatake area. Upper Toarcian age is indicated by the occurrence of *Grammoceras* and *Hammatoceras*.

(10) *Inoceramus hamadae* faunule (J3a)

Inoceramus hamadae HAYAMI* occurs in the Kaizara formation (Callovian)

in Kuzuryu area. The formation is mostly composed of ammonite bearing shales, and pelecypods are uncommon except some inoceramids, posidoniids and pectinids. "*Katroliceras*" *yokoyamai*, *Kepplerites* (*Seymourites*) *japonicus*, *K.* (*S.*) *acuticostum*, *K.* (*S.*) *kuzuryuensis*, "*Grossouvria*" *hikii* and some oppeliids are known, but the biostratigraphy of this formation should be further examined in future.

(11) *Inoceramus* cf. *nitescens* faunule (J3b)

Inoceramus cf. *nitescens* Arkell* and *I.* (?) *naganoensis* Hayami* occur in the "Nagano formation" of the Kuzuryu area. *Inoceramus nitescens* was established from the Corallian of England, and the occurrence of its comparable form agree well with the chronology suggested by *Kranaosphinctes matsushimai*. An inoceramid from the similar black shale of Shimohambara area seems close to cf. *nitescens*.

(12) *Latitrigonia tetoriensis* faunule (J2b)

This faunule is represented by *Latitrigonia tetoriensis* Kobayashi* *L. orbicularis* Kobayashi* and *Myophorella* (*Promyophorella*) *orientalis* Kobayashi and Tamura from the Oxfordian Yambarazaka formation of the Kuzuryu area. This faunule must be nearly coeval with the preceding, though the lithology is somewhat different from the "Nagano formation".

(13) *Nipponitrigonia sagawai* faunule (J3b)

Nipponitrigonia sagawai (Yehara), *Myophorella* (*Promyophorella*) *imamurai* Kobayashi*, *Nuculana* sp., *Coelastarte* sp., *Tancredia* sp. and *Protocardia* sp. are common in the Kiritani formation of the Jinzu area (Oxfordian). *Nipponitrigonia sagawai* has a wide life range in the Soma area and Outer Zone of Southwest Japan, but the acmaeic development of the species in the Inner Zone is very unique. *Sagawai*-like trigoniid occurs in the *Inoceramus furukawensis* bearing Sugizaki sandy formation of the Furukawa area, which can be correlated to the Kiritani formation.

(14) *Inoceramus maedae* faunule (J3b)

Inoceramus maedae Hayami* including several varietal forms is characteristic in the lower part (M_1 member) of the Mitarai formation of Makito area. This marine formation is generally assigned to the Oxfordian invasion phase, but the exact age is indeterminable.

(15) *Tetorimya carinata* faunule (J3b)

This faunule occurs in the tuffaceous siltstone of the middle part (M_2 member) of the Mitarai formation of the Makito area, and is composed of the following species: *Tetorimya carinata* Hayami*, *Nuculopsis* (*Palaeonucula*) *makitoensis* Hayami, *Modiolus maedae* Hayami, *Pinna* sp. ex gr. *sandsfootensis* Arkell*, *Pteria* (s. l.) sp., *Chlamys mitaraiensis* Hayami, *Protocardia* sp., *Oxytoma tetoriensis* and *Thracia shokawensis* Hayami. Most of these species occur also in the M_3 member but the frequency of each species is much different. *Tetorimya* seems characteristic in the Upper Jurassic (mainly Oxfordian) of the boreal region. *Pinna sandsfootensis* was originally described from the Corallian of England.

(16) *Entolium inequivalue* faunule (J3b)

This is also a characteristic faunule occurring in the black shales of the upper part (M₃ member) of the Mitarai formation of the Makito area, and consists of the following species: *Entolium inequivalve* HAYAMI*, *Solemya suprajurensis* HAYAMI*, *Paraeoneilo* sp.*, *Nuculopsis (Palaeonucula) makitoensis* HAYAMI, *Modiolus maedae* HAYAMI, *Brachidontes* (?) sp., *Oxytoma tetoriensis* HAYAMI*, *Chlamys mitaraiensis* HAYAMI, *Camptonectes* sp.*, *Limatula iwayae* HAYAMI*, *Pleuromya hidensis* HAYAMI*, *Tetorimya carinata* HAYAMI (rare) and *Thracia shokawensis* HAYAMI. This is one of the richest marine pelecypod faunule in the Hida region, but the distribution of these species outside the Makito area is unknown except for a comparable form to *Thracia shokawensis* from the shaly part of the Kiritani formation. As I noted elsewhere, *Entolium inequivalve* resembles closely *E. orbiculare* from the European Cenomanian and *E. nummularis* from the Volgian and (?) Valanginian of Siberia and Spitzbergen. Generally, this faunule seems to be related to boreal faunas instead of the Torinosu and Tethyan faunas.

(17) *Vaugonia yambarensis* faunule (? J3c or later)

Vaugonia yambarensis KOBAYASHI occurs in the conglomeratic Yambara formation of Kuzuryu area. But other marine pelecypods are unknown in the Itoshiro subgroup.

(18) "*Corbicula*" *tetoriensis* faunule

This is the most ubiquitous faunule in the brackish and non-marine beds of the Tetori group. "*Corbicula*" (*Mesocorbicula*) *tetoriensis* KOBAYASHI and SUZUKI* is accompanied by *Batissa antiqua* KOBAYASHI and SUZUKI*, *Pila nipponica*, *Malanoides vulgaris minima* in the Yanogidani formation of Furukawa, by *Batissa yokoyamai* KOBAYASHI and SUZUKI and *Melanoides vulgaris minima* in the Ushimaru formation of Makito, by "*Unio*" *ogamigoensis* KOBAYASHI and SUZUKI in Ogamigo, and by *Viviparus onogoensis*, *Pila nipponica*, *Melanoides vulgaris* and *M. vulgaris minima* in the Izuki formation of Kuzuryu. This faunule is thus found both in the Kuzuryu and Itoshiro subgroups, and the range may cover the greater part of the Upper Jurassic.

3) Nagato region

In the Nagato region the Jurassic System was represented by the Toyora and (?) Toyonishi groups, but the occurrence of pelecypods is restricted to a few horizons in the former group. In the lower part of the Toyora group considerable number of lower Liassic pelecypods occur fairly commonly, while in the middle-upper part ammonite-bearing shaly facies is predominant and pelecypods are quite rare except for several inoceramids and posidoniids.

(1) *Cardinia toriyamai* faunule (J1b, Locs. 53, 55, 57)

This is one of the richest faunules in the Japanese Jurassic, and found in the lower part (Nbc, Nbs by MATSUMOTO and ONO, 1947) of the Higashinagano formation in the Toyora area. It comprises the following species: *Cardinia toriyamai* HAYAMI*, *Nuculopsis (Palaeonucula)* sp., *Nuculana (Dacryomya) toriyamae* HAYAMI, *Parallelodon infraliassicus* HAYAMI*, *P.* cf. *infraliassicus* HAYAMI*, *P.* (?) *subnavicellus* HAYAMI*, *Grammatodon toyorensis* HAYAMI*,

Oxytoma cf. *cygnipes* (YOUNG and BIRD)*, *Chlamys textoria* (SCHLOTHEIM), " *Aequipecten* " *toyorensis* HAYAMI, " *A.* " sp., *Entolium* cf. *calvum* (GOLDFUSS), *Entolium* (?) sp., *Plicatula subcircularis* HAYAMI*, *Plicatula praenipponica* HAYAMI*, *Plagiostoma kobayashii* HAYAMI*, *P. matsumotoi* HAYAMI*, *Antiquilima nagatoensis* HAYAMI*, *Ctenostreon japonicus* HAYAMI*, *C.* sp., *Liostrea toyorensis* HAYAMI*, *Lopha sazanami* HAYAMI*, *Prosogyrotrigonia inouyei* (YEHARA) (varietal form), *Praeconia* cf. *tetragona* (TERQUEM)*, *Astarte* spp., *Fimbria* sp.*, *Sphaeriola nipponica* HAYAMI*, *Lucina hasei* HAYAMI*, *Cardium* (s. l.) *naganoense* HAYAMI*, *Neritopsis mutabilis* HAYAMI*, *N. elegans* HAYAMI*, *Promathildia* sp. ex gr. *turritella* (DUNKER)*, *Pictavia toyorana* HAYAMI*, *Pseudomelania* (?) sp., " *Dentalium* " sp., *Juraphillites* sp.*, *Rimirhynchia* sp.*, *Chomatoseris cyclitoides* (YABE and EGUCHI)* and *Isastrea* sp. The age must be somewhere in lower Lias. As I noted before (1959, p. 39), many species of the faunule are allied to the lower Liassic faunas of the Western Europe, north Africa, Amur, Sichota Alins and western Canada.

(2) *Prosogyrotrigonia inouyei* faunule (J1b, Locs. 52, 54, 56, 58)

Prosogyrotrigonia inouyei (YEHARA) is contained in the preceding faunule, but more abundant in the middle part of the Higashinagano formation. The associated species are *Nuculana* (*Dacryomya*) *toriyamae* HAYAMI, *Modiolus magatama* HAYAMI*, *Meleagrinella japonica* HAYAMI, " *Aequipecten* " *toyorensis* HAYAMI, *Entolium* cf. *calvum* (GOLDFUUSS) and *Plagiostoma matsumotoi* HAYAMI. *Chomatoseris cyclolitoides* is especially common in this part.

(3) *Oxytoma kobayashii* faunule (J1c, Loc. 59)

This faunule is found sporadically in the upper part of the Higashinagano formation, and consists of *Oxytoma kobayashii* HAYAMI*, *O. inequivalvis* (SOWERBY), *Meleagrinella japonica* HAYAMI, *Entolium* sp., *Plagiostoma* sp. and " *Lima* " sp.

(4) *Parainoceramus lunaris* faunule (J1e, Loc. 60, etc.)

Parainoceramus lunaris HAYAMI*, *Amonotis* n. sp.* (Pl. 1, Fig. 7) and many aptychi are characteristic in the lower part of the Nishinakayama formation (Ne zone). Associate ammonites, *Fontanelliceras* cf. *fontanellense**, *Fuciniceras primordium** and *Paltarpites toyoranus** indicate upper Pliensbachian age.

(5) *Parainoceramus matsumotoi* faunule (J1f, Loc. 61, etc.)

Parainoceramus matsumotoi HAYAMI* and its comparable forms are characteristic in the middle-upper part (Nd zone and partly Ng zone) of the Nishinakayama formation. They associated with *Hildoceras chrysantemum*, *H. inouyei*, *H. densicostatum*, *Harpoceras okadai*, *Peronoceras subfibulatum*, *Dactylioceras helianthoides* and some aptychi. This member was correlated to *Commune* and *Falcifer* Zones by ARKELL (1956).

(6) *Posidonia* sp. ex gr. *ornati* faunule (J1f, Loc. 62, etc.)

Posidonia sp. ex gr. *ornati* QUENSTEDT* forms a striking bed in the lower part of the Utano formation (Up beds) of the Toyora area (Pl. 1, Fig. 6). *Phymatoceras toyoranum* was found nearby, and the age is assignable to Aalenian.

(7) *Inoceramus* sp. ex gr. *fuscus* faunule (J1g, Loc. 62, etc.)

Inoceramus sp. ex gr. *fuscus* QUENSTEDT* occurs in the lower part of the Utano formation (Uh beds). *Hammatoceras* cf. *kitakamiense* and *Dumortieria*? sp. from this horizon suggest Aalenian age. *Inoceramus fuscus* is known in the Aalenian and lower Bajocian of Western Europe.

(8) *Inoceramus utanoensis* faunule (J2c or J3a, Loc. 81)

This faunule consists of *Inoceramus utanoensis* KOBAYASHI* and *I. ogurai* KOBAYASHI* from the upper part of the Utano formation. The age is unknown in detail, but the upper Middle Jurassic or lower Upper Jurassic in view of the resemblance of *utanoensis* with *Inoceramus kystatymensis* and *I. retrorsus* which are characteristic in the Bathonio-Callovian of boreal region.

These faunules include the main Jurassic pelecypod species hitherto known in the Kitakami, Hida and Nagato regions. Their life ranges should be further checked by more careful fossil-huntings, but such specific assemblages may serve to a certain extent for age determination of pelecypod-bearing strata which will be found in Japan and her surroundings in future.

Jurassic pelecypod genera have generally wide ranges and there are only a few useful genera for detailed chronology. But if compared with Upper

Table 4.

RANGE OF SOME CHARACTERISTIC PELECYPOD GENERA

genera	up. Triassic	low. Jurassic	mid. Jurassic	up. Jurassic	low. Cret.
P.(Torinosucatella)				—	
Modiolus(Inoperna)			—	—	
Somapteria				—	
Kobayashites			—		
Parainoceramus	- - - -	- - —	—		
Inoceramus		- -	—		
Radulonectites		—			
Somapecten				—	
Antiquilima		- - - -			
Ctenoides				—	
Prosogyrotrigonia	-	—			
Geratrigonia		—			
Vaugonia		—	—	—	- - -
Myophorella			—	—	—
Latitrigonia			—		
Nipponitrigonia			—		
Cardinioides		—	—		
Cardinia		—	- - - -		
Yokoyamaina		—			
Filosina					— - - -
Sphaeriola		- - - - -			
Burmesia	- -	—			
Neoburmesia				—	
Tetorimya				— - - -	

—— Japan   - - - World

Triassic faunas, the generic assemblage of Liassic faunas are clearly different. On the other hand no striking faunal gap exists between Upper Jurassic and Lower Cretaceous; it is very hard to distinguish the two by means of generic assemblage. The range of pelecypod genera frequently varies between Europe ane Pacific regions. *Oxytoma, Cadinia, Vaugonia, Coelastarte, Arcomytilus, Eomiodon* and some other genera seem to have appeared in Japan much earlier than in Europe. Several genera, which are treated in Table 4 seem to have appeared or disappeared at certain stages of Jurassic, and may be useful for rough estimaation of faunal age.

III.   Biofacies and Palaeoecology

As the result of my observations on the various fossil-coeneses in the Japanese Jurassic, it is concluded that the specific assemblage of pelecypods is closely connected with the mode of occurrence, lithofacies and therefore sedimentary environment. Since pelecypods are the most common fossil group in Jurassic of this country, they seem to constitute important facies-indicators for the palaeoecological work.

The Jurassic rocks of Kitakami, Hida and Toyora regions are mostly composed of terrigenous material, i. e. sandstones, shales and conglomerates. Pure limestone, dolomite, chert, phosphatic rocks, red beds and evaporites are unknown. In the Hida region detrital sediments unusually attain enormous thickness, and bituminous or carbonoceous sandstones and shales were rapidly accumulated in localized intermontane basins. The Kitakami region have been more flattened at that time: the topography is reflected in the comparatively thin sediments, scarceness of basal conglomerate and predominancy of ammonite-bearing shales showing calm deposition. Therefore, the sedimentary environment was probably somewhat apart from that of Hida.

In view of the rock- and bio-facies and their combination, however, there are many similar tendencies between the two regions. The Teradani formation of the Kuruma group and the Kaizara formation of the Tetori group are ammonite-bearing sandy-shales, and very similar to the Hosoura and Arato formations of Kitakami in the litho-facies and generic assemblage of pelecypods. The pelecypod faunules in the bituminous or carbonaceous rocks of the Hida region are fairly akin to those of the Shizukawa, Hashiura and Jusanhama groups in the generic assemblage and mode of occurrence. Such a facies is not predominant in the Toyora region but for some coaly layers near the base. But the change of litho- and bio-facies from the sandy Higashinagano to the shaly Nishinakayama formation is just comparable to the sequence from the Niranohama to the Hosoura formation in Kitakami. Taking rock-facies, mode of fossil-occurrence and faunal assemblage into consideration, the Jurassic fossiliferous sediments of these three regions can be roughly divided into three categories, namely, 1) Ammonite-facies, 2) Trigoniid-facies and 3) Cyrenoid-facies. These three facies are often seen in a stratigraphic column of one area. The trigoniid-facies (mainly littoral coarse

sandstone facies) is usually found at the passage from cyrenoid to ammonite-facies and *vice versa*, and indicates the initial or last stage of marine invasion into the basin, though trigoniid does not always occur. The ammonite-facies shows neritic and somewhat off-shore deposition, and the cyrenoid-facies lagoonal and sometimes brackish environment. The ratio of ammonite/pelecypod seem to support this interpretation. In the ammonite-facies ammonite species are generally not much smaller in number than pelecypod species, but in the trigoniid-facies ammonites are quite rare and fossils are mostly trigoniids, other thick-shelled pelecypods, belemnites and hexacorals. In the cyrenoid facies no ammonite has ever been found.

This division probably cannot be applied to the Upper Jurassic Torinosu group of the Outer Zone of Southwest Japan, because cyrenoid-facies is not represented and calcareous open-sea facies is very predominant. The distribution of the Torinosu pelecypods has been recently studied by TAMURA (1959–1960) in detail, and the Jurassic palaeoecology and facies division will become more complete by taking his data into consideration.

1) Mode of occurrence of organisms other than pelecypods

Before entering into the palaeoecological interpretation by pelecypods, I shall give a brief note on the distribution and mode of occurrence of ammonites, aptychi, belemnites, gastropods, brachiopods, hexacorals, echinoids and some other organisms found in the Jurassic of Japan.

(1) Ammonites and aptychi

Ammonites are fairly common in the neritic sandy shales or muddy shales which are more or less characteristic of the inundation phases in the Northeast and Inner Zone of Southwest Japan. In such shaly strata as the Nishinakayama, Hosoura, Teradani, Tsunakizaka, Kaizara and upper Kogoshio formations the individuals are assembled in some narrow and mainly massive part. *Parainoceramus, Inoceramus, Posidonia, Amonotis, Oxytoma* and *Variamussium* sometimes associate with ammonites in the Lower and Middle Jurassic, and *Inoceramus, Astarte, Limatula* and some other relatively thin-shelled pelecypods in the Upper Jurassic. The relation of shell-form of ammonites to sedimentary environment was observed by some authors. Sharp-edged discoidal ammonites with comparatively smooth surface are said to be common generally in fine-grained rocks such as marls and clays, while highly ornamented benthonic forms seem predominant in calcareous or detrital shelly facies. In the Japanese Jurassic discoidal or planulate species are fairly common in muddy or fine sandy facies, but thick and highly ornamented forms appear comparatively rare.

Aptychi (mainly "*Cornaptychus*"), ammonites' opercula, are fairly common in two horizons of the Nishinakayama shaly formation altogether with some thin-shelled and fragile pelecypods and small ammonites (Pl. 1, Figs. 2–4). There aptychi form more or less characteristic "Aptychien schiefer" in the highly fissile shales of Ne and Nd members which are composed of frequent alternation of whity silty and greyish muddy layers and show relatively calm

environment. It is supposed that aptychi and small ammonites have been transported to different places by weak current. The present isolated specimens of aptychi, especially the larger ones (figs. 2–3), are fairly similar to *Cornaptychus nagatoensis* NAGAO, 1932, from the same horizon in the external feature and outline. But it is difficult at present to determine their specific reference because there are more than two species of hildoceratids in the fossil bed. Aptychi *in situ* are quite rare, but a harpoceratoid ammonite, probably "*Hildoceras*" *chrysanthemum* YOKOYAMA, from the Nd beds has an operculum near its aperture (Pl. 1, Fig. 1). Though the whorls are flatly compressed, there is no doubt that the ammonite has not been drifted far from its habitat. In the Pliensbachian Teradani formation of the Kuruma group and the Upper Jurassic Sakamoto formation of the Torinosu group aptychi are known very sporadically. According to ARKELL (1956), "Aptychi are especially common in bituminous shales of the Toarcian and lower Kimmeridgian and in Tithonian limestones in many parts of the world." It is an interesting fact that these occurrences agree well with his statement.

(2) Belemnites

Belemnites often associate with ammonites in the neritic shales but are also common in more coarse-grained sandstones and coquina-like littoral deposits. The difference of the occurrence of belemnites from ammonites may be partly due to the brittle test which can be preserved in much more agitated condition.

(3) Gastropods

In the lower Higashinagano formation *Neritopsis*, *Promathildia* and *Pictavia* form striking fossil beds with *Grammatodon*, *Chlamys*, *Plagiostoma*, *Cardinia*, *Sphaeriola* and many other pelecypods (HAYAMI, 1960e). In the bituminous beds of the Shizukawa, Kuruma and Tetori groups brackish gastropods often associate with cyrenoid pelecypods (KOBAYASHI and SUZUKI, 1937, etc.). Jurassic gastropods are thus fairly common at certain horizons, but generally much rarer than pelecypods both in number of species and individuals. Gastropods at rocky shores are apt to be damaged and may be hard to be preserved in comparison with pelecypods. But the scarceness seems a general tendency both in the Triassic and Jurassic of Japan. More than 150 species of pelecypods were described from the Triassic of Japan, while only a few gastropods are known. I cannot adduce the reason with certain confidence, but maintain that the rarity may be partly due to the scarceness of calcareous deposits in the Triassic and Jurassic of the Kitakami, Hida and Nagato regions. In the Outer Zone the Upper Jurassic Torinosu group and upper Soma group contain nerineids and many other gastropods in the limestones and marls, while the coeval deposits are represented by clastic rocks in the North Japan and Inner Zone of Southwest Japan.

(4) Brachiopods

Generally, brachiopods except for lingulae seem common in more off-shore facies than normal pelecypods. In the Outer Zone rhynchonellids and terebratulids are commonly found in the limestones and somewhat siliceous shales

of the Torinosu group at Miyakodani, Sakawa and Nomazaki and the Nara-
dani formation at Sakawa and Sakamoto (TOKUYAMA, 1957, 1958, 1959; TAMU-
RA, 1960). But brachiopods are comparatively rare in the Kitakami, Hida
and Nagato regions. It may be also due to the scarceness of calcareous open-
sea deposits. Only a few rhynchonellids are found in the fine sandstones of
the Higashinagano and Aratozaki formations and black shales of the Kogoshio
formation. In the Aratozaki numerous valves of a small rhynchonellid are
contained in certain layers together with fragile right valves of *Oxytoma* and
some other thin pelecypods.

(5) Hexacorals

Many species of reef-building hexacorals were described by EGUCHI (1942,
1951) from the Torinosu limestone of the Outer Zone. *Isastraea* and some
other colonial corals are found also in the trigoniid-sandstones of the Kita-
kami and Nagato regions. They are hermatypic but probably not reef-
builders, since neither reef limestone nor bioherm is known in the regions.
The distribution of reef corals is restricted to the shallow clear waters of
tropics, but one must pay attention to the fact chat hermatypic corals survive
also in temperate areas without forming striking reefs. Some dendritic corals
are found in reworked pebbles of black impure limestone of the lower Kogo-
shio formation of Kitakami and remind one of their similarity to the Torino-
su limestone, but there is no other limy facies in the Kitakami, Hida and
Nagato Jurassics. The scarceness of corals in ammonite-bearing shales is
probably due to the inadequate factors for coral life. Although there is no
indication for the temperature of the sea-waters at present, it is highly pro-
bable that the stagnant muddy bottom condition and rapid sedimentation
arrested the development of reef corals. Solitary corals are abundant in the
lower Higashinagano and upper Kogoshio formations. *Chomatoseris cyclolitoides*
from the Higashinagano is hermatypic and probably a sandy inhabitant of
more or less agitated neritic or littoral condition. *Trochocyathus* (*Platycyathus*)
sp. from the Kogoshio is ahermatypic, and probably lived on muddy bottom
of fairly deep and cool condition. (HAYAMI, SUGITA and NAGUMO, 1960). The
small basal plate of the corallum suggest a calm environment. According to
WELLS (1956, 1957), *Trochocyathus* (*Platycyathus*) is known from the depth of
366–549 meters in recent seas, and there is a maximum development of
ahermatypic coral species between 180 and 360 meters, near the margins of
continental shelves in the "mud line" of MURRAY, though the distribution is
less restricted ecologically than hermatypics'.

(6) Stromatoporoids

Stromatoporoids often associate with hermatypic corals in the Torinosu
limestone (YABE and SUGIYAMA, 1940, 1935, etc.), but no definite specimen is
found in the Kitakami, Hida and Nagato Jurassics.

(7) Crinoids

Columnar stellates of a pentacrinid occur in the lower Higashinagano
formation (Pl. 2, Fig. 1). But no planktonic form is known in the Kitakami,
Hida and Nagato regions.

(8) Echinoids

Numerous spines and a few bodies of "*Cidaris*" are contained in the calcareous rocks of the Naradani, Torinosu and Soma groups, but echinoids seem uncommon in the Kitakami, Hida and Nagato regions. Only a few specimens were found in the Kogoshio, Teradani and Kaizara formations. Echinoids are generally said to dislike mud, which presumably clogs their water system and to be found of sandy or limy bottom under clear water. The rarity of echinoids in these regions is probably due to the inpredominancy of calcareous and clear water condition.

(9) Plants

The predominancy of fossil plants is a striking feature in the bituminous beds of the Inner Zone of Southwest Japan. Many species of plants were described or listed by Yokoyama, Oishi, Kimura and others from the Kuruma and Tetori groups. Gregarious plant beds are generally considered as brackish or non-marine sediments, because no marine fossils are found therein. In the Kuruma group especially the Kitamatadani, Negoya and Shinatani formations plant beds with *Cladophlebis*, *Nilssonia*, *Equisetites*, *Dictyophyllum* and other leaves alternate with cyrenoid shell-banks characterized by *Bakevellia*, *Eomiodon* and *Crenotrapezium*. Such a relation between plants and cyrenoids is seen also in the Tetori group, Iwamuro and Yamaoku formations. In the Kitakami and Nagato regions the Jurassic is represented properly by marine deposits, and plant beds are restricted to several horizons of the lower Niranohama, Ogino-hama, Mone and Kogoshio formations of Kitakami and Utano formation of Nagato. Drift woods are, however, fairly common in marine beds especially in the ammonite-bearing shales of Kitakami and Nagato. The oldest fossil forest in this country is known in the upper Liassic Shinatani formation. Many giant stems of *Equisetites* stand subvertically to the bedding plane, and *Eomiodon* beds and striking ripple marks are found near its base. The fact reminds enough one of the *Equisetites* forest, which grew near the shore of an embayment.

2) **Pelecypod facies in the Kitakami Jurassic**

The change of bio-facies and sedimentary environment of the Kitakami region is well typified by the sequence of the Shizukawa area. I intend to describe and discuss the biofacies of the Lower Jurassic on the basis of the field observation in the environs of Shizukawa in some detail, and then to deal with generalities.

(1) Lower Jurassic biofacies in the environs of Shizukawa

As stated in the article for stratigraphy, the Jurassic sedimentation of Shizukawa area began with the lower Niranohama formation under profound embayment condit on. The bituminous rock-facies, abundance of cyrenoid pelecypods and absence of ammonites, belemnites and other purely marine organisms tell that it was accumulated in a kind of lagoonal condition, where waters may have been stagnant. There are abundant bituminous material and pyrite deposits which were probably originated in hydrogen sulphide.

The embayment must have been restricted from open sea in its front by a spit or a certain barrier, which prevented waves and coastal currents from entering. Little is known of the salinity of the embayment, but it was presumably not much lower than open sea, so far as can be judged from the assemblage of pelecypod genera. The fauna of the lower Niranohama formation has been called "cyrenids", because of the misidentification of two species with *Cyrena* (=*Corbicula*), a brackish or fresh-water genus in Tertiary and Recent times. But as the result of my palaeontological study they are most certainly nearly marine. Besides, *Palallelodon, Modiolus, Bakevellia, Isognomon, Pteria* (s. l.), "*Ostrea*", *Geratrigonia, Thracia, Cuspidaria,* (?) and *Burmesia* are found in association with them (HAYAMI, 1958c, 1959a etc.). The occurrence of *Camptonectes* in the same horizon of the Mizunuma area may support this interpretation, since pectinids probably cannot survive under much decreased salinity. Most trigoniids are characteristic in the neritic or littoral deposits such as the overlying upper Niranohama formation. But *Geratrigonia* alone is very predominant in these cyrenoid beds not only in Shizukawa but also Hashiura and Mizunuma areas.

Fossils, chiefly *Eomiodon* (?) *giganteus* in the less bituminous sandy layers of the Niranohama (Nh$_3$ member), seem sometimes autochthonous in view of the scattered occurrence and subvertical orientation of the comissure plane. However, most fossils of the lower Niranohama are very crowded in several banks and, if pelecypod valves are intact with ligaments, must be allochthonous. Generally speaking, in a stagnant embayment, oxygen is gradually decreasing and hydrogen sulphide increasing towards the bottom, where black muds are accumulated and no organisms but for anaerobic bacteria can inhabit. These crowded fossils were presumably derived from the communities which flourished in less reducing and probably shallower environments. Generic and specific assemblages of pelecypods is much different among fossil beds, but two types of community can be distinguished. In some beds *Geratrigonia, Isognomon, Pteria* (s. l.) and some other genera indicating high salinity occur commonly with *Bakevellia, Modiolus, Eomiodon* and *Yokoyamaina* (*Geratrigonia*-subfacies), while in some other banks the former three genera cannot be found and the fauna is composed of the latter four genera (*Bakevellia*-subfacies). *Bakevellia* and *Eomiodon* are probably euryhaline genera, and could adapt to wide environment of unstable salinity. Incidentally it has been known that the number of constituent species decreases in brackish faunas and that the number of individuals, however, often become larger than marine ones. THIENEMANN's law seems to hold true in this case.

In some shaly layers *Thracia, Cuspidaria* (?) and juvenile *Bakevellia* and *Eomiodon* are gregariously assembled. These thin pelecypods may be inhabitants on muddy bottom, but the differential occurrence may be partly due to the sorting by weak currents. "*Ostrea*" has a marked tendency to make extremely crowded banks which look at a glance limestone layers and to exclude other pelecypods. It is probably due to temporal explosive propagation of oysters in the embayment.

The cyrenoid-bearing bituminous rocks merges upwards with the very coarse sandstones of the upper Niranohama formation with striking *Vaugonia* banks. Numerous valves of *Vaugonia, Cucullcea* and *Coelastarte* form many banks, but no intact specimen is found. The shells are often fragmental and surface-ornaments frequently effaced mechanically by waves. Sometimes gastropods, belemnites and hexacorals associate with them, but organisms with thin shells are scarcely met with. At the basal part a thin layer of shell sands is found and cross-laminations are often developed. The overlying sandy shales (Ns$_2$ member) show striking intraformational foldings, and their reworked pebbles are abundantly contained in trigoniid-banks. These facts indicate that the sedimentation was carried out under fairly agitated waters of littoral zone. I cannot presume that the vaugoniid fauna was living in such a condition, because in modern sandy beaches the strongly agitated waters may forbid the life of pelecypods except for a few subplanktonic forms such as *Donax* which show unique method of rhythmic migration near the shore-line.

Generally a thanatocoenesis of recent benthonic mollusks at sandy beach is mostly composed of littoral and inner neritic elements which are the inhabitants of about 30 meters at the deepest. The constituents of the upper Niranohama fauna seem to have derived from such a range of depth. There are a few individuals of *Bakevellia, Isognomon, Geratrigonia* and *Eomiodon* which are quite predominant in the embayment facies of the lower Niranohama. They were probably derived accidentally from the lagoons behind a certain barrier.

The uppermost part of the Niranohama formation is composed of finer well-sorted sandstones. *Vaugonia* occurs sporadically, and *Meleagrinella* and *Camptonectes* are characteristic in certain layers. This suggests less agitated and slightly more off-shore environment, and I distinguish it as *Meleagrinella-*subfacies from typical trigoniid sandstones.

The fine sandstones of the uppermost Niranohama alternate with and passing gradually into the dark grey sandy shales of the Hosoura formation. Its lower part (Hi member by SATO, 1957) is composed of well stratified sandy shales with considerable amount of sandy intercalations and yields *Vaugonia* and *Variamussium* at some localities. Free circulation of waters can be expected for the lithology. Its main part (Ha, Hl, Hh members by SATO, 1957) is dark and massive muddy shales and bears many calcareous nodules at the top. These members are believed to have been deposited in more off-shore and calm environments than the trigoniid-sandstones and *Variamussium-*sandy shales. Fossils are never autochthonous in the Hosoura formation but do not form so crowded beds as in the Niranohama. Sometimes thin intercalations of black sandstone are observed in Hl and Hh members, and *Trigonia, Vaugonia* and some other coastal pelecypods are crowded. In several cases it is very difficult to determine from field observation whether they are lenticular fossil beds or reworked pebbles of the underlying trigoniid-sandstone.

Ignoring these pelecypods, the organisms of the Hosoura sea are confined

to ammonites, belemnites, several thin-shelled pelecypods such as *Inoceramus* (s. l.), *Pinna*, *Posidonia* and ill-preserved drift woods. Many individuals of *Posidonia* form colonies in the upper part. The Hosoura formation was deposited probably on neritic calm bottom, but the abundance of bituminous matter suggest that the environment was still limited from open sea by a certain barrier. In the Mizunuma area contemporaneous black shales yield some pelecypods of embayment facies, and trigoniid-sandstone is not developed. It may imply the presence of a meridional bay which was closed to the south.

The Aratozaki sandy formation covers disconformably the noduliferous muddy shales of the Hosoura formation. Its basal part (As$_1$ member) yields *Cucullaea*, *Modiolus* (*Inoperna*), *Oxytoma*, *Camptonectes*, *Entolium*, *Ctenostreon*, *Trigonia*, *Vaugonia*, *Myophorella*, *Coelastarte*, *Isocyprina*, *Fimbria* (?), *Pholadomya*, minute ammonites, rhynchonellid and massive hexacorals in some small lenticular fossil banks along the basal plane. *Oxytoma* and brachiopod are especially common in thin layers of fine sandstone. The generic assemblage of pelecypods is at a glance similar to that of the upper Niranohama fauna, but the constituent species are much larger in number, in spite of the smaller number of individuals. Pectinids and some other pelecypods with relatively thin shells are common in this fauna and indicate neritic character rather than littoral. Considering the wide distribution of this fauna in the Kitakami region, the bio-facies may imply wider and less restricted environment than the trigoniid-sandstones of the Niranohama.

The main part of the Aratozaki formation is composed of conglomeratic coarse sandstones of littoral or deltaic origin, but its palaeoecology is not clear, since no fossils are contained except for some cyrenoids in bituminous intercalations. The small fauna comprises *Kobayashites*, *Isognomon*, *Protocardia* and *Eomiodon* (?) and suggests that a certain local lagoonal condition may have been produced temporally at the time of the sedimentation of the coarse-grained material.

The second transgression and inundation in this area are indicated by the monotonous deposition of the Arato shaly formation. But the scarceness of fossils except for a few ammonites and inoceramids makes it difficult to analyze the palaeoecology by the change of bio-facies. In the lower part there are many sandy intercalations on which curious Lebensspuren are sometimes impressed (Pl. 1, Fig. 9). They are probably the crawling prints of a certain gastropod in shallow sea bottom or tidal flat. The overlying noduliferous muddy shales are lithologically similar to the uppermost part of the Hosoura formation, though the size of nodules is much smaller. The main part of the Arato formation is monotonous sandy or muddy shales and was deposited in off-shore and calm environment. The litho- and bio-facies are similar to the Hosoura formation in many aspects, and the two typify the ammonite-facies in the Kitakami and the Inner Zone of Southwest Japan.

(2) Cyrenoid-facies

Cyrenoid-facies, well typified by the lower Niranohama formation of Shizukawa, Hashiura and Mizunuma, are found at some other horizons in the south

Kitakami region, showing similarly enclosed environments.

In the Tsukinoura formation of Ojika, *Kobayashites*, *Parallelodon*, *Bakevellia* and *Eomiodon* form striking fossil banks in bituminous black shales. They seem to interfinger with *Chlamys*- and *Ctenostreon*-bearing coarse ferruginous sandstones towards the southwest, and it is highly probable that the *Kobayashites* beds were deposited in a stagnant lagoon which was isolated from an agitated sea of the south or west side.

The upper half of the Kitakami Jurassic is represented mainly by purely marine deposits except for some plant beds in the Mone, Kogoshio and Ogino-hama formations, and cyrenoid fauna has not been found. The Jusanhama group of the Hashiura area, which may be Lowermost Cretaceous, bears strikingly crowded fossil beds with *Filosina*, *Crenotrapezium*, *Protocardia*, *Corbula* (?) and *Cuspidaria* (?). The mother rock is not very bituminous, but the bio-facies is distinctly of this category.

(3) Trigoniid-facies

The gregarious occurrence of trigoniids (mainly *Vaugonia* and *Myophorella*) is intimately connected with coarse non-bituminous sandy lithology which shows littoral and much agitated environment. Such trigoniid sandstones, typified by the upper Niranohama formation of Shizukawa, are found at many horizons especially in the Kitakami and Soma Jurassics. The faunas of the lower Kosaba formation of Karakuwa and the Kodaijima formation of Ojika are nearly coeval with the Aratozaki fauna of Shizukawa, Hashiura and Mizu-numa, and bear similar specific assemblages and mode of occurrence. The trigoniid sandstone of the Kosaba formation seems to pass gradually into *Iso-gnomon*- and *Lopha*-bearing slightly bituminous sandstone towards the north, and the embayment at that time may have been open to the south. The trigoniid beds of the Tsukinoura formation is lithologically comparable with the upper Niranohama, but *Chlamys*, *Ctenostreon* and other neritic genera associate with *Vaugonia*.

In the Upper Jurassic of Kitakami, trigoniid sandstones are found in the Tashiro sandstone (upper Kozumi formation) of Ojika and the upper Mone formation of Karakuwa. *Myophorella* (*Promyophorella*) is the main constituent of the faunas, and *Myophorella* (*Haidaia*), *Nuculana* and some other neritic pelecypods occur in association in the latter beds. *Myophorella* (*Promyophorella*) is fairly common in the Kogoshio formation and Nagasaki-Isokusa blocks of Karakuwa, but it does not form striking trigoniid sandstones and occur in shales of much finer grain-size together with *Grammatodon*, *Astarte*, *Pinna* and other neritic (or even pelagic) pelecypods and ammonites.

The sand-grains of this facies are variable in size and mineral assemblage. The sandstones of the Niranohama and Aratozaki formations are fairly quartzose, while the Tashiro sandstone is very arkosic. The difference may be, however, due to the different states of backland instead of maturity or sedimentary environment, since Upper Jurassic sandstones of Kitakami and Soma regions are always much more arkosic than Middle and Lower Jurassic ones.

(4) Ammonite facies

Most individuals of Jurassic ammonites in the Kitakami region have been found in dark grey or black sandy or muddy shales such as the Hosoura and Arato formations of the Shizukawa area. A few specimens are found in sandy formations such as the Niranohama, Aratozaki and Kodaijima, but they seem rather accidental. The Samuraihama formation of Ojika and the Tsunakizaka formation of Karakuwa show similar litho- and bio-facies to the Arato formation of Shizukawa, Hashiura and Mizunuma. In the Tsunakizaka formation pelecypods are rare in comparison with ammonites, but *Inoceramus* and *Posidonia* are fairly common at some localities.

The upper part of the Kogoshio formation of Karakuwa and the main part of the Kozumi formation of Ojika are composed of black muddy shales and assigned to this category. But the generic assemblage of pelecypods are much different from the above mentioned ammonite beds of the Lower and Middle Jurassic. *Inoceramus* and *Posidonia* are unknown, while ammonites are usually accompanied by rich pelecypods such as *Nuculana* (*Praesaccella*), *Parallelodon, Grammatodon, Entolium, Limatula, Myophorella, Astarte* and *Pleuromya*. Such a generic assemblage is commonly seen in the shaly formations of the upper Soma and Torinosu groups, and indicates probably less restricted environments than *Inoceramus*-shales. The Kogoshio pelecypods are mostly small in size, and the tendency is seen also in the shaly formations of the Torinosu group. But it is not due to dwarfing by geographical isolation, since corresponding species are equally small in more sandy formations. The common occurrence of *Variamussium* cf. *habunokawense* and its exclusive tendency as seen in the Isokusa block suggest deep and more or less pelagic condition. OYAMA (1952) studied the ecological distribution of pectinids and noted *Propeamussium* and *Palliorum* can survive on deep muddy bottom where *Chlamys* and other pectinids cannot inhabit. Similar mode of life can be expected for *Propeamussium* and *Variamussium*, judging from the similar shell morphology. Such an ecology of *Variamussium* was studied also in the Torinosu group by TAMURA (1960d), and its coexistence with some species of *Entolium* and *Limatula* was announced. *Trochocyathus* (*Platycyathus*) is probably another facies-indicator of outer neritic or bathyal environment for the upper part of the Kogoshio formation.

3) Pelecypod Facies in the Hida and Nagato Jurassic

In the Jurassic of the Hida region cyrenoid-facies is very predominant, and bituminous or carbonaceous sandstones and shales occupy the greater part of all stratigraphical columns. Trigoniid sandstones are comparatively undeveloped in the lower half, though ammonite shales are found in some invasion stages. On the contrary in the Nagato region ammonite-facies is the most predominant, and trigoniid sandstones are restricted to the basal part, and cyrenoid-facies is absent at all. Thus the Jurassic fossiliferous rocks of the Inner Zone of Southwest Japan can be roughly divided also into three facies, though the proportion among the three is much different among areas. Since there are only a few common pelecypod species among Kitakami, Hida

and Nagato, it is difficult to compare the bio-facies with that of Kitakami. However, as to the relation between the bio- and litho-facies there are many similar tendencies.

(1) Cyrenoid-facies

Bituminous (or carbonaceous) cyrenoid- and plant-bearing sandstones and black shales are widely distributed in the Kuruma group (inclusive of the Iwamuro and Yamaoku formations) and Tetori group which were sedimented in intermontane basins. The Kitamatadani, Negoya, Shinatani and Tsuchiza-wa formations of the Kuruma group bear gregarious *Eomiodon* beds at many horizons. Other ubiquitous genera are *Mytilus* (*Falcimytilus*), *Bakevellia*, *Iso-gnomon* and *Crenotrapezium*, and they are frequently accompanied by *Chlamys*, " *Camptonectes* ", *Radulonectites*, ostreids, *Cardinioides*, *Protocardia* and *Homomya*. These pelecypod beds are often adjacent to plant beds and probably accumulat-ed under stagnant condition of profound embayment. Since pectinids cannot inhabit in much decreased salinity, the cyrenoid-fauna may be properly marine just as the lower Niranohama fauna of Kitakami. But in some cases, only *Bakevellia*, *Eomiodon* and *Crenotrapezium* form fossil banks. The absence of pure marine elements in such banks may indicate somewhat unstable salinity. The abundance of pyrite and chalcopyrite of sedimentary origin in the fossil beds is noticeable. It cannot be concluded always that the pelecypods are actually inhabitants in such a reduced condition, for none is exactly autoch-thonous except for a few doubtful cases. But pelecypods are often bivalved and free from secondary destruction and water-wear, and their transportation may be negligible in comparison with other facies.

The cyrenoid beds in the Iwamuro and Yamaoku formations contain similar pelecypod species to the Kuruma fauna, and the sedimentary condition is generally considered to be nearly the same.

" *Corbicula* " beds are commonly found in the Jurasso-Cretaceous Tetori group. The generic assemblage of the beds is, however, fairly different among localities, as pointed out by KOBAYASHI and SUZUKI (1937). At Ushimaru of the Makito area " *Corbicula* " (*Mesocorbicula*) and *Batissa* associate with *Ostrea* and some other brackish elements, while at Izuki of the Kuzuryu area main associated mollusks are *Pila*, *Melanoides* and *Viviparus*, and no definite marine or brackish genus is found. Anyhow, the smaller number of constituent pelecypod species and absence of any definite marine element may suggest restricted environment and much decreased salinity.

(2) Trigoniid-facies

Trigoniid sandstone is generally undeveloped in the Kuruma group, but the non-bituminous sandstones at the passages from ammonite-facies to cyrenoid-facies show similar lithological aspect to the trigoniid-facies of Kita-kami. The lower part of the Shinatani formation is composed of well-sorted fine-medium massive sandstones, yielding *Chlamys*, " *Camptonectes* " and *Oxytoma*. Pectinid-bearing medium sandstone at Kamikawara of the Kuruma area is also comparable with this facies.

In the Tetori group (Kuzuryu subgroup) trigoniid-facies show local deve-

lopment in Jinzu, Furukawa, Arimine and Kuzuryu areas, of which the Kiritani conglomeratic sandstone of Jinzu with numerous valves of *Nipponitrigonia* and a few *Myophorella*, *Coelastarte*, *Nuculana* and *Tancredia* is the most striking. Similar assemblage is known also in the Sugizaki formation of Furukawa. *Myophorella* and *Latitrigonia* are known in the Yambara conglomerate and Yambarazaka sandy formations of Kuzuryu, but they do not form fossil banks.

In the Toyora region, similar sandstones are distributed in the basal part of the Higashinagano formation, and represent the initial stage of early Liassic transgression. As noted elsewhere (HAYAMI, 1959i), this formation does not yield trigoniids but for *Prosogyrotrigonia*, but the mode of occurrence, generic assemblage and lithology bear alliances to the trigoniid sandstones of Kitakami, especially to the lower Aratozaki formation. Hermatypic hexacorals, brachiopods, columnar stellates of a pentacrinid and highly ornamented gastropods are associate with the pelecypods in the fossil banks. The predominant pelecypod genera of the sandstone are *Parallelodon*, *Grammatodon*, *Chlamys*, "*Aequipecten*", *Entolium*, *Plicatula*, *Plagiostoma*, *Liostrea*, *Cardinia*, *Lucina* and *Sphaeriola*. No intact specimen of pelecypod is found, and thin pelecypod shells and apertures of gastropods are often broken. The fact suggests that the sedimentary condition is attributable to fairly agitated littoral and/or neritic bottom. The fossiliferous sandstone merges upwards with finer bluish sandstone of more off-shore origin which contains sporadically *Meleagrinella*, *Oxytoma*, *Entolium* and *Plagiostoma*. This subfacies may be ecologically corresponding to that of the *Meleagrinella* sandstone of the uppermost Niranohama formation of Kitakami.

(3) Ammonite-facies

Ammonites and inoceramids are fairly common in the Hida and Nagato regions, and their occurrence is properly confined to this facies characterized by dark grey or black sandy of muddy shales. The lithology is almost equal to the ammonite-facies of Kitakami, but in these two regions there are somewhat deviated subfacies characterized by the common occurrence of posidoniids, pectinids, myacids and aptychi.

In the Kuruma group of the Hida region the Teradani and Otakidani ammonite-bearing silty shales wedge themselves into the sequence of bituminous rocks (KOBAYASHI et al., 1957). They constitute two inundation phases. Inoceramids and posidonids are unknown at present in the formations, but the pelecypod faunules consisting of *Variamussium*? and *Pleuromya* in the Teradani and of *Geratrigonia* and *Oxytoma* in the Otakidani are quite different from other faunules of the Kuruma group. The Y_2 beds of the Yamaoku formation (KONISHI, 1954) bear *Nuculana*, *Meleagrinella* and some marine pelecypods, and lithologically belong to this facies.

The ammonite-facies developed in the Toyora group where the Lower to Middle Jurassic sequence is mostly occupied by ammonite- and inoceramid bearing muddy shales. The Nishinakayama formation is generally rich in ammonites and inoceramids (mainly *Parainoceramus*), and comprises also some

characteristic aptychi- and *Amonotis*-shales at definite horizons. A considerable amount of thin valves of *Amonotis* are concentrated in a thin layer of the lower Nishinakayama formation (Ne beds) (Pl. 1, Fig. 7). The aptychi-shales in Ne and Ng beds show similar appearance (Pl. 1, Figs. 2, 3, 4). Thin valves of *Parainoceramus* and small ammonites occur in the shales, but no larger organism with heavy test is found in association. The lithology of the *Amonotis*- and aptychi-shales is well characterized by the numerous thin whity silty layers which alternate frequently with greyish muddy part and cause the high fissility of the rocks. The *Posidonia*-shales in the Up beds of the lower Utano formation (Pl. 1, Fig. 6) is not so fissile, but the fossil occurrence is very similar to the above cases. It may be rather inadequate to compare their sedimentary conditions to the "Aptychienschiefer" and "Posidonienschiefer" in Swabia and some other areas of Western Europe, whose petrography and bituminous matter have been precisely studied by many authors. But it is certain that these subfacies indicate very calm and stagnant bottom condition of an inland sea, where only thin shells such as aptychi could be differentially derived from their habitat.

The main part of the Utano formation yields some plant fossils, but is mostly occupied by marine sandy shales which contains inoceramids and a posidoniid in the upper part.

The Kaizara and Yambarazaka formations and their comparable marine strata are extensively distributed in the lower Tetori group (Kuzuryu subgroup) of the Hida plateau region. Perisphinctoids occur fairly commonly in the silty or muddy shales. *Inoceramus* seems to have adapted to the environment, and many individuals are found at many localities. But the specific assemblage is quite different among Kaizara, Nagano, lower Mitarai and Sugizaki formations. As noted before (HAYAMI, 1960c), small forms are predominant in the Kaizara and Nagano formations of Kuzuryu, while the Mitarai forms are quite large and inequivalve and remind at a glance one of certain Cretaceous species. The pelecypod fauna of the Mitarai formation (HAYAMI, 1959f, g) is the richest one in the ammonite facies of this country. It consists of *Solemya*, *Nuculopsis* (*Palaeonucula*), *Palaeoneilo*, *Modiolus*, *Pinna*, *Oxytoma*, *Chlamys*, *Camptonectes*, *Entolium*, *Limatula*, *Protocardia*, *Pleuromya*, *Tetorimya* and *Thracia* besides *Inoceramus*. The absence of trigoniid and scarceness of heterodont pelecypods with thick tests are noticeable. A whity tuffaceous siltstone is inserted in the middle part of the formation, where *Modiolus*, *Pinna* and *Tetorimya* occur sporadically showing autochthonous occurrence, as illuminated by MAEDA (1952b). Pectinids and myacids are more predominant in the dark muddy shales of the upper part. These pelecypods were probably fond of calm, muddy and somewhat deep bottom of inland sea.

4) **Ecological distribution of pelecypod genera***

The occurrence of the following pelecypod genera is confined to some

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* The mode of occurrence of many Upper Jurassic pelecypods in the Soma and Torinosu groups studied by TAMURA (1959, etc.) is also taken into consideration.

definite sedimentary environment, if a few exceptional cases are ignored.

Parallelodon (s. s.) and *Cucullaea* (s. l.) are most common in gregarious trigoniid sandstones, but *Grammatodon* is found also in more off-shore facies. *Parallelodon* (*Torinosucatella*) is restricted to open-sea environment. All genera are quite rare in cyrenoid-facies.

Modiolus occurs in various facies, but *Modiolus* (*Inoperna*) could live in coastal environment of purely marine waters and *Mytilus* (*Falcimytilus*) is most predominant in embayment condition of somewhat unstable salinity.

Bakevellia shows a marked development and attain large size in the bituminous shales and sandstones of deep embayment facies in Kitakami and Hida regions, and almost always associate with *Eomiodon* and mytilids. Triassic and Cretaceous bakevelliids in Japan often occur in purely marine deposits and even in limestones, but in the Jurassic such an occurrence is not found.

Isognomon lives at present in littoral or neritic clear water of tropical and subtropical seas. Jurassic species except for subgenus *Mytiloperna*, are probably sessil benthos as Recent ones in view of the wide byssal gape, but their occurrence is restricted properly to bituminous cyrenoid-facies and only a few specimens were found in trigoniid- and ammonite-facies. *Inoceramus* and *Parainoceramus* are, on the contrary, most common in neritic silty shales and often associate with ammonites and *Posidonia*. Only a few specimens are found in trigoniid sandstones such as the lower Aratozaki and Kodaijima formations. It is a marked tendency that these three genera are absent at all in the calcareous facies of the Outer Zone of Southwest Japan.

Oxytoma and *Meleagrinella* form characteristic communities in neritic fine sandstones which seem to be slightly more off-shore than normal trigoniid sandstones. A few specimens are known in neritic silty shales.

Entolium and *Variamussium* are probably free-swimming scallops. The former is common in various neritic sandstones and shales, but the latter is restricted to more or less pelagic off-shore deposits. *Chlamys* and *Camptonectes* are neritic inhabitants but sometimes occur in trigoniid sandstones and even cyrenoid shales. *Plicatula* seems a stenopic group since it is very common in certain trigoniid sandstones but quite rare in other facies.

The occurrence of *Plagiostoma* and *Ctenostreon*, which are believed to have adhered to certain objects by means of byssi, is restricted to littoral and neritic sandstones, and trigoniids and pectinids are often found in association. But limids may be generally more stenohaline than pectinids in view of the absence of the former in the cyrenoid facies. Free swimming *Limatula* may have lived generally in more off-shore environment than other groups of the Limidae, and often is accompanied by *Entolium* and *Variamussium*.

Geratrigonia could live exceptionally in profound embayment condition altogether with *Bakevellia*, *Isognomon* and *Eomiodon*, but other trigoniids are restricted to purely marine conditions and form striking banks in agitated littoral coarse sandstones. They are also found in neritic shaly sediments, but it seems a general tendency that trigoniids in shales are smaller in size

than those in sandstones.

Cardinia and *Coelastarte* occur in littoral and neritic sandstones with trigoniids, prionodonts and other pelecypods with heavy tests. *Astarte* seems more euripic but their occurrence is restricted to pure marine deposits and unknown in cyrenoid-facies. Most species hitherto listed as *Astarte* from such embayment facies, if they have concentric sculptures, may be referable to *Eomiodon* and some other genera of the Neomiodontidae.

Eomiodon is characteristic in bituminous shales and sandstones of deep embayment origin, and quite ubiquitous in the Lower and Middle Jurassic cyrenoid-faunas of Japan. The genus must have been able to adapt to unstable salinity. *Crenotrapezium*, *Filosina* and *Yokoyamaina* may have lived in similar environments. "*Corbicula*" (*Mesocorbicula*) and *Batissa* in the Tetori group are probably brackish or non-marine inhabitants, since it never associate with definite marine organisms.

Myacids with thin tests probably cannot adapt to much agitated condition. In view of their deep pallial sinus and mode of occurrence, they seem to have adapted to soft bottom of calm environment. *Pleuromya*, *Pholadomya* and *Tetorimya* occur in neritic silty or muddy shales, and *Burmesia* and *Cuspidaria* (?) in bituminous shales of embayment facies. *Thracia* seems quite euripic but occurs always in shales.

ECOLOGICAL DISTRIBUTION OF SOME JURASSIC
PELECYPOD GENERA IN JAPAN (schematized)
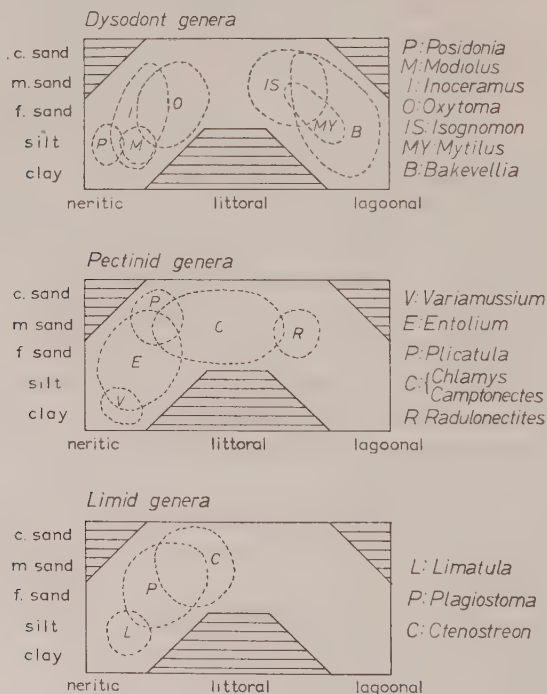
Fig. 2–1.

According to TAMURA's and my observations on the Soma and Torinosu pelecypod faunas, *Entolium*, *Variamussium*, *Limatula* and *Ctenoides* are common in shaly part, *Plagiostoma*, *Camptonectes*, *Plicatula* and large species of trigoniids in sandstones, and pteriids and *Neoburmesia* in marly or limy rocks. *Grammatodon*, *Astarte* and *Protocardia* occur in various rock-types. Though the generic assemblage of the Soma-Torinosu fauna is much different from those of Kitakami and the Inner Zone, there are many similar tendencies about the ecological distribution of pelecypods. The tendencies also agree to a certain extent with GIGNOUX's observation (1926) on the European Jurassic pelecypods.

The ecological distribution of above mentioned pelecypod genera in the Kitakami, Hida and Nagato Jurassics is summerized in Fig. 2. The grain-size of mother rocks, which may reflect the nature of bottom, is an easily determinable factor (vertical axis). The degree of environment restriction (horizontal axis) is presumed from the maturity of grains, the ratio of ammonite/pelecypod, bituminous matter and mode of fossil occurrence, and the determination may be inevitably more or less subjective. But the distinctness of lithology and bio-facies among ammonite- (neritic), trigoniid- (littoral) and cyrenoid- (embayment) facies are fairly clear in the Jurassic areas dealt with in this paper, and it can be well ascertained from many stratigraphical columns that the trigoniid-facies appear at the passages from cyrenoid-facies to ammonite-facies and *vice versa*.
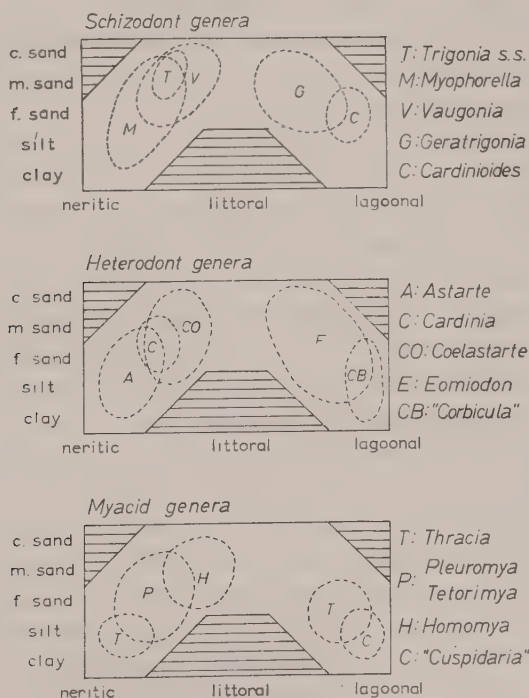
Fig. 2-2.

IV. Palaeobiogeography

In Japan Jurassic sedimentary basins are highly localized. The fauna of each sedimentary region bears many characteristic elements and is clearly different from those other regions. It may be partly due to the heavy dependence of pelecypod distribution on sedimentary facies, but must be dependent also upon certain biogeographic isolation. Since the distribution is much related to litho-facies, the assemblages of pelecypod genera, which are summerized before, seem to represent to a certain extent some physico-chemical states of sedimentary environments (depth, bottom nature, salinity and state of water agitation). On the other hand, similar specific assemblages between two isolated regions must imply an intimate sea connection. If one finds two contemporaneous faunas of isolated basins are composed of similar genera and subgenera but quite different in specific assemblage, one can generally consider that their biogeographical connection is not intimate. In this article I estimate the faunal connections among various Jurassic sedimentary basins based on SIMPSON's indices for faunal resemblance, and discuss the palaeobiogeography in relation to the Jurassic surface feature of Japanese islands which can be deduced from many stratigraphical points. I intend also to make a brief review on the distribution and characters of the Jurassic pelecypods in the Indo-Pacific regions on the basis of many previous works.

1) Palaeobiogeography of Early Jurassic Sea in Japan and its Surroundings

It seems reasonable to consider the Jurassic biogeography of Japan separately in the early (Hettangian-Aalenian), middle (Bajocian-Bathonian) and later (Callovian-Berriasian) periods.

SATO (1956) noted that the Liassic ammonite faunas of the Toyora, Kuruma and Shizukawa are composed of fairly different elements, and that the localization must be explained by the discrepancy of sedimentary period or the sea connection with different trends. The Pliensbachian and Toarcian ammonites of the Toyora group (MATSUMOTO and ONO, 1947) bear a considerable amount of Tethyan (especially Italian) elements such as *Fontanelliceras* and *Fuciniceras* (ARKELL, 1956). The Pliensbachian ammonites of the Kuruma group are the mixture of a Tethyan element, *Canavaria*, and a boreal one, *Amaltheus* (SATO, 1955). The Sinemurian and Aalenian ammonites of the Shizukawa group is generally represented respectively by *Arnioceras* and *Hammatoceras* which are common in the southeastern Asia and some other areas of Pacific region. Bajocian and Aalenian ammonites of Alaska are said not to be boreal, and SATO (1956) noted the *Tmetoceras* fauna of the Hosoura formation shows marked affinities with those of south Alaska.

Similar localization is seen also in the Liassic pelecypod faunas. The pelecypod faunas of the Shizukawa, Kuruma and Toyora groups are respectively composed of 40, 52 and 48 forms (including species, subspecies, and varieties). However, there are only a few comparable species among the three groups (see Table 5). *Eomiodon vulgaris* occurs commonly in the cyrenoid

shales of the Shizukawa and Kuruma groups, and *Entolium* cf. *calvum* does in the neritic sandy facies of the Kuruma and Toyora groups. But most other pelecypods are endemic in each sedimentary region. These three palaeobiogeographical provinces seem distinct in Early Jurassic times. The Kitakami province is well characterized by the prolific occurrence of *Geratrigonia*, *Vaugonia* and other trigoniids. The appearance of *Vaugonia* already in the Lower Lias is a striking feature in the Kitakami province. To the bituminous embayment conditions may have adapted *Bakevellia*, *Isognomon*, *Modiolus* and *Eomiodon* and some aberrant genera such as *Geratrigonia* and *Yokoyamaina*. It is of special interest that *Burmesia*, which is characteristic of the Noric-Rhaetic of Upper Burma, Indochina and Moluccas, occur in the basal part of the Kitakami Jurassic. If the resemblance of Sinemurian and Aalenian ammonites between Kitakami and Moluccas is also considered, the sea of Kitakami may have been intimately connected with the southwestern Pacific region.

In the Kuruma faunal province the cyrenoid faunas show a splendid development, adapting to the bituminous environment of profound embayment. *Bakevellia*, *Isognomon*, *Mytilus* (*Falcimytilus*), *Eomidon* and *Crenotrapezium* are represented by many forms and quite abundant, forming gregarious fossil banks. The generic assemblage is similar to the cyrenoid fauna in the similar facies of the Kitakami province, but the greater part is specifically distinct. The scarceness of cosmopolitan elements and predominance of specialized genera and species suggest a restricted province for the Kuruma fauna. *Cardinioides* and *Radulonectites* are two endemic genera of this province. The former genus is restricted to the Inner Zone also in Upper Triassic times.

The lower Liassic Higashinagano fauna of the Toyora province bear some cosmopolitan elements such as *Oxytoma inequivalvis*, *O.* cf. *cygnipes*, *Chlamys textoria*, *Entolium* cf. *calvum*, *E,* cf. *lunare* and *Praeconia* cf. *tetragona*. These species were originally described in Europe, and some of them later reported from the Lias of Madagascar, Moluccas, Amur, Sichota Alins, Alaska, Alberta, Nevada, Neuquén and some other regions of the world. Other Higashinagano species are mostly new, but their allied species are frequently found in the Lias of Europe, North Africa and Pacific regions. The resemblance of the pelecypods to the Amur fauna described by KIPARISOVA (1952) is noteworthy, since the connection of the Toyora sea to the north has not been reported. The Tethyan similarity of the Pliensbachian and Toarcian inoceramids and posidoniids agrees well with that of the ammonite fauna. The flourish of *Posidonia* and *Parainoceramus* in the upper Lias is known also in the western Tethys region especially in Alps and Caucasus. In the eastern Tethys region, however, Liassic fauna is not represented enough to discuss further the sea connection between eastern Asia and Europe.

If the occurrence of *Haugia japonica* (NEUMAYR) from "Mitoda of Sakawa basin" is erroneous, there is no indication for the presence of Lias in the Outer Zone of Southwest Japan. But in view of the similar assemblage of Torinosu pelecypod genera to Higashinagano, Liassic pelecypods, if discovered in the Outer Zone in future, may be composed of similar elements to the

Higashinagano fauna.

Simpson (1959) mentioned several indices to express the degree of faunal resemblance between two isolated areas and discussed their adequacy in various cases. One of his indices, $\frac{100C}{N_1}$, is introduced here and calculated about the faunal resemblance among Lower Jurassic pelecypod species and genera (independently) of Shizukawa, Iwamuro, Kuruma, Yamaoku and Toyora areas. Here N_1 is the number of constituent species (or genera) of smaller fauna, and C is common species (or genera) between two faunas. Comparable species, subspecies and doubtful occurrence are counted as 0.5. In Table 5, the numerator is the index of specific resemblance and the denominator of generic resemblance. In this case, it is safely concluded that the Toyora fauna is quite different from other faunas both in specific and generic assemblages. The Shizukawa fauna is fairly similar to the Kuruma in generic assemblage but specifically quite different. The Iwamuro and Yamaoku faunas, though their constituents may be too small to discuss the palaeobiogeography, seem to be quite intimate to the Kuruma fauna.

Table 5.

FAUNAL RESEMBLANCE IN THE LOWER JURASSIC

fauna	species/genera	Shizukawa	Iwamuro	Kuruma	Yamaoku	Toyora	
SHIZUKAWA	$\frac{40}{27}$		$\frac{1}{2}$	$\frac{2}{15.5}$	$\frac{1}{4}$	$\frac{0}{7.5}$	number of common species / number of common genera
IWAMURO	$\frac{5}{5}$	$\frac{20.0}{40.0}$		$\frac{3}{4}$	$\frac{3}{3}$	$\frac{0}{0}$	
KURUMA	$\frac{52}{26}$	$\frac{5.0}{59.6}$	$\frac{60.0}{80.0}$		$\frac{3}{4}$	$\frac{1}{8}$	
YAMAOKU	$\frac{6}{6}$	$\frac{16.7}{66.7}$	$\frac{60.0}{60.0}$	$\frac{50.0}{66.7}$		$\frac{0}{1}$	
TOYORA	$\frac{48}{31}$	$\frac{0}{27.8}$	$\frac{0}{0}$	$\frac{2.1}{30.8}$	$\frac{0}{16.7}$		
		Simpson's formula			$\frac{100C}{N_1}$		

2) **Palaeobiogeography of Middle Jurassic Sea in Japan and its Srroundings**

The Bajocian Aratozaki fauna of Kitakami bears some allied forms to cosmopolitan species, such as *Oxytoma münsteri, Camptonectes auritus, Entolium disciforme* and *Ctenostreon proboscideum*. But the occurrence of *Vaugonia* (s. s. and *Hijitrigonia*), *Cucullaea* and *Coelastarte*, some of which are hardly distinguishable from the species of the lower Liassic Niranohama formation, reminds one of the peculiarity of the Kitakami province in the Lias. *Inoceramus morii* from the Aratozaki and *I.* cf. *lucifer* from the Tsunakizaka formation are intimate respectively to *I. subambiguus* from the Aalenian of Okhotsk and *I.*

lucifer from the Bajocian of Alaska and Prince Patrick. In this period stephanoceratids seem to have travelled far to the northern area, and there may have been certain temporal faunal connection with those regions. Middle Jurassic pelecypod faunas seem rather rare in other regions than Kitakami mountainland. A trigoniid fauna of the Bajocio-Bathonian Awazu formation of Soma comprises *Vaugonia. Latitrigonia, Ibotrigonia* and *Nipponitrigonia*, and is more akin to Upper Jurassic faunas than Lower Jurassic ones in general aspect. TOKUYAMA (1958) noted that the brachiopod fauna of the Narakani formation of the Sakawa basin is of Bajocio-Bathonian, but associated pelecypods are too poor to be regarded as the representatives of the fauna on the Pacific coast. It is of special interest that *Inoceramus utanoensis* from the upper Utano formation of the Toyora area is probably conspecific with *I. kystatymensis* from the Bathonian of Lena. It may be an element of boreal sea, since its allied species such as *I. retrorsus* seem very characteristic in the Bathonian-Callovian of Siberia and Greenland. But no associated species with the *Inoceramus* are known in the upper Utano formation, and the palaeobiogeographical relationship with other regions cannot be further discussed.

3) Palaeobiogeography of Late Jurassic Sea in Japan and its Surroundings

The late Jurassic sedimentary areas are much different from early Jurassic ones. Four palaeobiogeographic provinces are distinguished in the Upper Jurassic of Japan: they are Kitakami, Hida (Tetori), Soma and Torinosu provinces.

In many areas of the Kitakami region the Middle and Upper Jurassic overlaps the Lower, and marine realm was much more extensive. But the number of pelecypods is rather inferior to the Lower both in species and individuals. It is probably because of the scarceness of embayment and littoral deposits where normal pelecypods are most common. The Upper Jurassic pelecypods of Kitakami are quite different from those of the Hida region (Tetori group) except for *Myophorella (Promyophorella) orientalis*, but bear many similar elements to the Soma and Torinosu faunas. *Myophorella (Haidaia) crenulata* from the Mone formation of Karakuwa suggests the similarity of the Mone fauna to that of the "*Lima*-sandstone" of the Nakanosawa formation in Soma. The Tithonian and Berriasian pelecypods of the Kogoshio formation bear many common or comparable species to the faunas of the Nakanosawa and Koyamada formations of Soma, Kurisaka formation of Sakuradani-Kito, Yatsuji formation of Sakawa and Sakamoto formation of Kuma, such as *Parallelodon (Torinosucatella) kobayashii, Grammatodon takiensis, Nuculana (Praesaccella)* sp. ex gr. *yatsushiroensis, Entolium kimurai* and *Variamussium* cf. *habunokawense*,

ARKELL (1956, p. 429, 599) noted that lower Kimmeridgian Mexican ammonite, *Idoceras*, occurs in the Arato formation of Shizukawa, and emphasized the uninterupted sea-connection across the Pacific. SATO (1958) suggested the generic assemblage of the Tithonian-Berriasian ammonites from the Kogoshio formation is similar to that of Mexico. And similar assemblages were sub-

sequently reported from Colombia (HAAS, 1960) and Peru (RIVERA, 1951, DIAZ, 1959). Therefore, the Upper Jurassic sea of Kitakami must have been intimately connected with the Torinosu sea and Pacific ocean at that time.

The pelecypod fauna of the Tetori group is, however, quite different from those of Kitakami, Soma and Torinosu except for a few trigoniids. The neritic species from the Mitarai formation of Makito, as I (1959f, g) described in detail, bear some comparable forms to the Upper Jurassic (and Lower Cretaceous) of Western Europe, Ural, Lower Yenisei and Alaska. Considering also the occurrence of *Kepplerites* (*Seymourites*) from the Callovian Kaizara formation, the Tetori fauna is composed in part of boreal species. *Inoceramus* cf. *nitescens* from the Nagano formation and *Pinna* sp. ex gr. *sandsfootensis* from the Mitarai resemble Corallian species of England, but most other species, especially the cyrenoids* in the embayment facies, seem indigenous to the Tetori basin. As to ammonites, two forms from the Arato and Oginohama formations of Kitakami have been compared respectively with *Kepplerites* (*Seymourites*) *acuticostum* and *Kranaosphinctes matsushimai* from the Callovio-Oxfordian of the Kuzuryu area.

As discussed precisely by TAMURA (1959d, 1960a-c), the Upper Jurassic pelecypod faunas of the Nakanosawa and Koyamada formations of the Soma group are intimate with the Torinosu fauna of Shikoku and Kyushu. 61 Soma species and 76 Torinosu species were described by YABE and SATO (1942), KIMURA (1951, 1956) and TAMURA (1959a-d, 1960a-d), of which 25 species occur in common between the two provinces. Moreover, *Modiolus bipartitus*, *M.* (*Inoperna*) *plicatus*, *Arcomytilus laitmairensis*, *Pinna mitis*, *Camptonectes browni*, *Myopholas acuticostata*, *Pholadomya somensis* and *Homomya gibbosa* are known widely in the Upper Jurassic of Europe, Somaliland, Kenya and Cutch, and the occurrence of identical or comparable specimens with them in the Soma and Torinosu groups is quite important for palaeobiogeographical consideration. KRUMBECK (1905) pointed out that the several species of *Cidaris*, *Terebratula*, *Alectryonia* (=*Lopha*) and *Nerinea* in the Torinosu limestone are identical or allied to those of the " Glandarienkalk " in Lebanon. Although none of the Glandarienkalk pelecypods is as yet found in Japan, the generic assemblage seems similar to the Soma-Torinosu fauna. It is, however, a marked difference between the Torinosu and Etyopian provinces that *Eligmus*-*Gryphaea* fauna is unknown in the former. The generic assemblage of trigoniids is also somewhat different. *Trigonia* (s. s.), *Indotrigonia*, *Laevitrigonia*, *Iotrigonia* and *Pterotrigonia* flourished in the Upper Jurassic (especially Argovian and Tithonian) of Cutch (KITCHIN, 1903 ; COX, 1952), but those genera are unknown in the Upper Jurassic of Japan. On the other hand, *Latitrigonia*, *Myophorella* (*Promyophorella* and *Haidaia*), *Linotrigonia* and *Nipponitrigonia* which often form trigoniid banks in the Soma-Torinosu province and sometimes in Tetori

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* " *Corbicula* " *tetoriensis* KOBAYASHI and SUZUKI was announced from the Sichota Alins region, but the species was said to coexist with some elements of the Lower Cretaceous Ryoseki fauna.

basin, but scarcely known in Cutch and Etyopian province. It may be rightly concluded that the Soma-Torinosu fauna includes many characteristic genera and species of the Pacific region besides a considerable amount of Tethyan elements.

Table 6.

FAUNAL RESEMBLANCE IN THE UPPER JURASSIC

fauna	$\dfrac{species}{genera}$	Shishiori +Ojika	Soma	Tetori	Torinosu	number of common species / number of common genera
SHISHIORI + OJIKA	$\dfrac{26}{19}$		$\dfrac{4.5}{12}$	$\dfrac{1}{9}$	$\dfrac{4}{14}$	
SOMA	$\dfrac{69}{42}$	$\dfrac{17.3}{63.2}$		$\dfrac{2}{14}$	$\dfrac{25}{26}$	
TETORI	$\dfrac{43}{29}$	$\dfrac{3.8}{52.6}$	$\dfrac{4.7}{48.3}$		$\dfrac{1}{10}$	
TORINOSU	$\dfrac{77}{40}$	$\dfrac{15.4}{73.7}$	$\dfrac{36.2}{65.0}$	$\dfrac{2.3}{34.5}$		
		Simpson's formula $\dfrac{100\,C}{N_1}$				

SIMPSON's indices (Table 6) calculated among the four Upper Jurassic faunal provinces of Japan seem to reflect well the sea connection among the Kitakami, Soma and Torinosu provinces and also the isolation of the Tetori fauna from those of Pacific side.

Examining widely distributed species in detail, it is noticed through the Jurassic that most of them occur in neritic sandy or calcareous facies except for a few comparable forms to foreign species in muddy facies. The lower parts of the Higashinagano, Aratozaki and Nakanosawa formations, which bear the greater part ef cosmopolitan species in Japanese Jurassic, are composed similarly of fine to medium-grained sandstones (sometimes calcareous), which were deposited on shallow bottom under free circulation of waters. On the other hand, in restricted basins such as Kuruma and Tetori, conditions were apt to become peculiar and unstable, and cosmopolitan elements could not settle, notwithstanding the fact that several specialized genera and species show striking local development.

4) " Eo-nippon Cordillera " and its bearing on the Jurassic palaeobiogeography

KOBAYASHI (1941, 1947) opined that " Eo-nippon Cordillera " appeared by the Rhaetic Toyogatake and the Middle Jurassic Hida emergences in relation to the Sambagawa metamorphism and pre-Ryoseki intrusion of the Sakawa orogenic cycle. He noted further that the Jurassic litho- and bio-facies in the Inner Zone of Southwest Japan are much different from those of the Outer Zone, and that the " Eo-nippon Cordillera " formed a land barrier between the

two sedimentary suits, just as the "Vindelizische Gebirge" between the Alpine and German facies in Triassic period.

In fact, the Upper Jurassic faunas of the Tetori group are different in many respects from those of the Soma-Torinosu groups. Reef-building hexacorals, stromatoporoids, calcareous algae, *Cidaris*, *Nerinea* and brachiopods are common in the calcareous facies of the Soma-Torinosu groups, but scarcely met with in the Inner Zone. The faunal discordance is well reflected also in the generic assemblage of pelecypods. In the Soma-Torinosu faunas *Parallelodon* (*Torinosucatella*), *Grammatodon*, *Modiolus* (*Inoperna*), *Pteroperna*, "*Aequipecten*", *Somapecten*, *Variamussium*, *Ctenostreon*, *Ctenoides*, *Exogyra*, *Myophorella* (*Haidaia*), *Opis*, *Pholadomya*, *Neoburmesia* and *Goniomya* are important constituents, but those genera are scarcely found in the marine beds of the Inner Zone. On the other hand, the important genera of the Tetori marine fauna such as *Nuculopsis* (*Palaeonucula*), *Oxytoma*, *Inoceramus*, *Posidonia* and *Tetorimya*, are unknown in the Outer Zone. *Modiolus*, *Pinna*, *Chlamys*, *Entolium*, *Limatula*, *Protocardia*, *Thracia*, *Pleuromya* and *Solemya* were described commonly in the two suits, but are represented by quite different and unrelated species. A similar tendency is found in the ammonite faunas: none of the Tetori ammonites was ever found in the Torinosu and Soma groups, though the main ammonite beds of the Tetori group may be slightly older than those of the Outer Zone.

The Oxfordian Kiritani and (?) Sugizaki formations of the Hida region show somewhat unique bio-facies in the Inner Zone. As noted by IMAMURA (1933, 1959) and KOBAYASHI (1956) the former formation bears *Nipponitrigonia sagawai* which is common in the Soma-Torinosu groups. The fossil occurrence seems to me fairly similar to the shell banks of the Kambaradani sandstone of the Torinosu group in the Sakawa basin, though the age of the Kiritani beds is probably older than the Kambaradani. For the similarity KOBAYASHI (1947) presumed the presence of "Kurisaka channel" which crossed diagonally the Eo-nippon Cordillera and stretched from eastern Shikoku to the Tetori basin. But the presence of the channel cannot be endorsed by other ammonite and pelecypod species.

The Upper Jurassic fauna of the Kitakami province is intermediate between the Tetori and the Soma-Torinosu provinces in many respects. The Callovian and Oxfordian faunas from the Arato and Oginohama formations bear *Seymourites*, *Kranaosphinctes*, *Inoceramus* and *Posidonia*, and is quite different from the Soma-Torinosu faunas, while the Kimmeridgian (?), Tithonian and Berriassian faunas from the Mone, Kogoshio and Kozumi formations show marked similarity to the non-calcareous formations of the Outer Zone. It can be readily imagined that the Tetori and Torinosu seas were connected in North Japan where the "Eo-nippon Cordillera" decreased its height.

The significance of the "Eo-nippon Cordillera" on the Jurassic biogeography is thus very important. The Recent molluscan communities of the Japan Sea coast is fairly different from the Pacific coast, but the Jurassic biogeographical isolation is no less striking than the Recent case.

The development of the land barrier can be traced back into Early Jurassic times. Since no Liassic fossil is known in the Outer Zone, it is now difficult to make clear the faunal isolation in Early Jurassic times. But if one presumes that the Liassic fauna in the Outer Zone is composed of similar genera to the Soma-Torinosu faunas, the more or less specialized pelecypods of the Kuruma and Shizukawa groups must be extraneous from the Outer Zone. The similarity of the Iwamuro and Yamaoku faunas to the Kuruma fauna suggests that the land barrier at that time was situated somewhat more southwards than the present watershed. The generic assemblage of the Higashinagano pelecypods is fairly similar to the Torinosu fauna, though none of them is actually conspecific. Among 27 genera of the Higashinagano fauna, 5 are extinct already by the Upper Jurassic and 15 are represented also in the Soma-Torinosu fauna sometimes by intimate (probably descendant) species. Taking the Tethyan similarity of the Upper Liassic ammonites and inoceramids into consideration, the Toyora sea was situated near the western end of the land barrier and opened mainly to the south. The sea may have connected also to the Kuruma basin and further to the Amur geosynclinal region, passing through the rear side of the land barrier.

The Upper Triassic faunas of the Inner and Outer Zones of Southwest Japan have been analized enough to consider the biogeography. The Carnic faunas of the Mine, Nariwa, Nabae and Kochigatani groups have several characteristic elements in respective areas but at the same time intimately connected with one another. The Mine group in the Inner Zone is more than 10 times thicker than the contemporaneous Kochigatani group of the Outer Zone, but there are many common pelecypods between the two regions. The Noric fauna is not yet completely analyzed, but the *Entomonotis* fauna seems to have spread very widely both in the Outer and Inner Zones. Therefore,

Table 7.

DISTRIBUTION OF MESOZOIC CYRENOID(PLANT) BEDS

tectonic province / age	Inner Zone of S.W. Japan	Kitakami (west belt)	Kitakami (east belt) and Soma	Outer Zone of S.W.Japan & Northern Kitakami
Lower Cretaceous	Yoshimo Tochio	Jusanhama	Ofunato Oshima Ayukawa	Monobegawa Ryoseki Omoto
Upper Jurassic	Izuki Numamachi Ushimaru		(Kogoshio) (Mone) (Oginohama)	
Middle Jurassic		Aratozaki	(Tochikubo) Hatsuno Tsukinoura	
Lower Jurassic	Iwamuro Yamaoku Shinatani Negoya Kitamatadani	Mizunuma Niranohama		
Upper Triassic	(Nariwa) Mine			

Table 8.

DISTRIBUTION OF MESOZOIC TRIGONIID SANDSTONES (TRIGONIID-BEARING BEDS)

tectonic province / age	Inner Zone of S.W. Japan	Kitakami (west belt)	Kitakami (east belt)	Soma	Outer Zone of S.W. Japan
Lower Cretaceous			(Oshima) (Isokusa) (Nagasaki)		Yamanokami
Upper Jurassic	Yambara Sugizaki Arimine Kiritani Yambarazaka		Kogoshio Tashiro Mone	Koyamada Nakanosawa Yamagami	Kambaradani (Sakamoto) (Kurisaka) Yatsuji
Middle Jurassic		Aratozaki	Tsukinoura Kosaba	(Awazu)	
Lower Jurassic	(Otakidani) Higashinagano	(Hosoura) Niranohama	Kodaijima		
Upper Triassic	Heki (Nabae) (Mine)				(Usugatani)

KOBAYASHI's opinion that the Eo-nippon Cordillera was developed by the Rhaetic Toyogatake and succeeding emergencies can be well endorsed from the palaeobiogeographical point of view.

It is interesting to see the zonal migration of cyrenoid-bearing embayment facies from the Inner to the Outer Zone (Table 7). Gregarious fossil banks with *Eomiodon* and some other cyrenoids appeared already in the lower Lias in the Hida region and the western belt of Kitakami, and *Anodontophora* banks in the Carnic of the Nagato region show similar bio-facies. In the eastern belt of Kitakami and Soma the first appearance of eomiodontids can be dated as Bajocian. In the Outer Zone of Southwest Japan and northern Kitakami region the development of such cyrenoid-facies is unknown until the Lower Cretaceous Ryoseki epoch. A similar tendency is found as to the distribution of plant beds. Upon KOBAYASHI's suggestion OISHI divided the Mesozoic floras into the "Rhaeto-Liassic *Dictyophyllum* suit" and the "Wealden *Onychiopsis* suit". Many floras belonging to the former suit occur in the Triassic Mine, Nariwa and Shidaka groups and the Liassic Kuruma, Iwamuro and Yamaoku formations of the Inner Zone, while the suit is unknown in the Outer Zone. The first striking flora in the Outer Zone is found in the Lower Cretaceous Ryoseki group. The discrepancy is, I think, attributable to the different topographical state of the two zones in the Jurassic times; that is to say, intermontane and deep embayment conditions did not predominate in the Outer Zone where the foregone Akiyoshi orogeny gave less effect than in the Inner Zone.

5) Distribution of Jurassic Pelecypods in the Indo-Pacific Regions

I intend to make a brief review on the distribution, assemblage and main previous works of the Jurassic pelecypods in the Indo-Pacific regions, which I could refer to for this study. For convenience I divide the regions into several provinces in accordance with ARKELL's division (1956).

(1) Indian Peninsula and Himalayas (Cutch, Baluchistan, Attock, Ferghana, Karakorum, Spiti and Upper Burma)

Since OPPEL (1863) and STOLICZKA (1866) described some Jurassic pelecypods from Himalayas, many important works were published by European authors.

Nuculopsis (*Palaeonucula*), *Inoceramus*, *Aucella*, *Lima* (mainly *Plagiostoma* and *Limatula*), *Trigonia*, *Astarte* and some other thin-shelled pelecypods from the Spiti shales were monographed by HOLDHAUS (1913). The fauna is somewhat similar to those of Moluccas and 3N-arc, and very important for the correlation and palaeogeographical consideration in cooperation with the rich ammonites. The bio-facies of the Spiti shales, I presume, is somewhat allied to that of the ammonite shales in the Northeast and Inner Zone of Southwest Japan. KITCHIN (1903) described many trigoniids from the marine coastal facies of Cutch on the shallow shelf of Gondwana. COX (1937, 1940, 1941, 1952) greatly contributed to the description of the Middle and Upper Jurassic neritic fauna of Cutch and general classification of Mesozoic pelecypods. About 120 species of palaeotaxodont, prionodont, dysodont, isodont and schizodont pelecypods were monographed by the authority. *Nuculopsis* (*Palaeonucula*), *Nuculana* (*Praesaccella*), *Nuculana* (*Dacryomya*), *Grammatodon* (s. s. and *Indogrammatodon*), *Modiolus* (s. s. and *Inoperna*), *Oxytoma*, *Bakevellia*, *Gervillella*, *Isognomon* (*Mytiloperna*), *Eligmus*. *Chlamys*, *Eopecten*, *Camptonectes*, *Entolium*, *Plicatula*, *Plagiostoma*, *Liostrea* (s. s. and *Catinula*), *Gryphaea*, *Lopha* and *Trigonia* seem predominant. The Cutch fauna is different from those of the Himalayan geosynclinal region in the scarceness of *Inoceramus* and *Aucella*, but it may be chiefly due to the contrary sedimentary environment. According to COX, a considerable amount of the Cutch pelecypods occur also in western Europe. The abundance of *Indogrammatodon*, *Eopecten*, *Eligmus* and *Gryphaea* shows the Cutch sea was intimately connected with East Africa. The generic assemblage of trigoniids such as *Indotrigonia*, *Laevitrigonia*, *Iotrigonia* and *Pterotrigonia* seems characteristic of the Indo-African region.

According to REED (1931, 1936), the *Eligmus-Gryphaea* fauna is found also in the Bathonian Namyau beds of Upper Burma. The development of *Eomiodon* in the Bathonian seems a striking feature of the Tethyan region. Bathonian species of the genus were hitherto reported from the Great Oolite and Great Estuarine series of England (MORRIS and LYCETT, 1853; LYCETT, 1863; COX and ARKELL, 1948; ANDERSON and COX, 1949), the Larzac beds of south France (COX and MAUBEUGE, 1950), Madagascar, Kuar Bet beds of Cutch and Attock district (COX, 1935) besides the Namyau beds. In many places of those areas, *Eomiodon* is accompanied by *Protocardia*, *Corbula* and *Bakevellia*, and the

assemblage and lithology indicate a certain embayment condition just as the
cyrenoid faunas of Japanese Lias. In fact, the Bathonian *Eomiodon* beds
appear prior to the *Macrocephalites*-bearing pure marine deposits belonging to
the Upper Jurassic transgression.

In contrast with the abundance of Bathonian and later pelecypods, earlier
species seem much rarer in the Indian region. Only several trigoniids, limids
and pectinids are known in the Lias of Baluchistan (HOLLAND, 1909), Spiti
(STOLICZKA, 1866) and Attock (COX, 1935). Some Bajocian species were
announced from Karakorum (STAESCHE, 1932). Most of those species have
been said to be identical with European or Madagascar faunas, but the analysis
may not be satisfactory to make a biogeographical interpretation.

(2) Indochina and Indonesia (Tonkin, Laos, Annam, Cochin China, Thailand,
Malay (?), Sumatra, Borneo, Timor, Moluccas)

In this region Jurassic pelecypods are known in Phu-nhoquan, Sontay and
Na Cham of Tonkin, Tchepone and Sam Nena of northeast Laos, Hun-Nien
of Annam, Trian of Cochin China, Mae Sot and Chumphon of Thailand, (?)
Singapore, Jambi of middle Sumatra, Sambas and Sarawak river of Borneo,
southwest Mindoro of Philippine, Taliabu, Buru, Misol and Ceram of Moluccas
and Timor.

Liassic species seem fairly common in Indochina (COUNILLON, 1909 ; MANSUY,
1914, 1919a, b). Many species were compared with European famous pelecypods,
and the elongate forms of *Cardnia* are also of European type. Middle and
Upper Jurassic species are rare except for a few pectinids and limids des-
cribed by MANSUY (1920). Taking the occurrence of *Gryphaea arcuata* in
some *Uptonia* beds (FROMAGET, 1952) also into consideration, the Jurassic
pelecypod fauna of Indochina is more intimate with Europe and Indian regions
than north Pacific region. *Astarte, Goniomya*, etc. were described by NEWTON
(1906) from Singapore, but SCRIVENOR (1931) is of opinion that the age is pre-
Rhaetic. The *Eomiodon* beds at the mouth of Chumphon river of south Thai-
land (HAYAMI, 1960a) may be related to the Bathonian fauna of the Indian
region.

In Sumatra and Borneo the occurrence of Jurassic pelecypods is rather
sporadical. *Astarte, Opis, Protocardia, Corbula*, etc. described by KRAUSE (1896),
VOGEL (1896, 1899–1902), NEWTON (1903), and FRECH and MEYER (1922) from
the (?) Middle Jurassic of Jambi and Sarawak are endemic species, and only a
few are comparable with the faunas of Indian region. As pointed by KOBA-
YASHI (1957b), *Trigonia molengraffi* NEWTON from Borneo is referable to
Myophorella (*Haidaia*) which is fairly characteristic in the Upper Jurassic of
north Pacific region. KOBAYASHI (1957) described *Solemya, Latitrigonia, Ruti-
trigonia, Myophorella* (*Promyophorella*), *Nipponitrigonia* and *Chlamys* from the
Upper Jurassic or Lower Cretaceous along the Amaga river of Mindoro, and it
is quite interesting that some of them are identical or comparable with certain
Tithonian and Neocomian trigoniids in the Outer Zone of Japan. HAYASAKA
(1943) described a trigoniid near Mansaley of this island, which was refered
to *Vaugonia* by KOBAYASHI and MORI (1955). *Vaugonia* shows special develop-

ment in the Lower-Middle Jurassic of Japan, and the faunal connection be-
tween Mindoro and Japan is generally thought to be very close. Unfortunately,
most of these fossil beds in western Indonesia and Philippine are not yet
firmly dated, and the range of each species cannot be estimated in accuracy.
But it is evident that the faunas comprise many different elements from
Indian region.

Eastern Indonesia region including Taliabu, Buru, Misol, Ceram, Jamdena,
Timor and Rotti is important for the consideration of pelecypod evolution in
the western Pacific. The rich Liassic, Callovian and Oxfordian species were
described chiefly by German and Dutch authors. Liassic *Palaeonucula*, *Gram-
matodon* and *Trigonia* from Misol (WANDEL, 1936) show European affinity, but
the middle Liassic fauna of Timor and Rotti includes many aberrant forms
such as *Gervilleioperna*, *Lithotis*, *Mytilus*, (?) *Nucula*, " *Myophoria* ", *Opisoma*, ?
Pachymegalodus, " *Schafhäutlia* and *Paradoxia* (KRUMBECK, 1923). *Gervilleioperna*
is known also in the middle Lias of North Africa (DUBAR, 1948), but all
species are unknown outside Timor and Rotti, suggesting a distinct small
province from other areas of this region. Middle Jurassic pelecypods are
known in Misol, and most forms are said to be identical with or allied to
European species (SOERGEL, 1913; JAWORSKI, 1920; WANDEL, 1936), such as
Camptonectes lens, *Entolium demissum*, *Ctenostreon pectiniforme*, *Plagiostoma
semicirculare* and *Oxytoma münsteri*. But it seems more reasonable to regard
that those forms are cosmopolitan elements, since they are mostly found also
in the Bajocian of Japan and South America. The Upper Jurassic faunas of
Moluccas are different from the Lower-Middle ones in generic assemblage and
are well characterized by the prolific occurrence of coarse-ribbed *Inoceramus*
(the group of *I. galoi* in my classification, 1960c), *Aucella* and *Posidonia* (BOEHM,
1907, 1912; HUMMEL, 1923; KRUMBECK, 1923, 1924; WANDEL, 1936). The *Ino-
ceramus*-bearing shaly facies is extensively distributed in the Oxfordian, and
the fauna shows an intimate sea connection with Spiti of Himalaya and 3N-
arc region. However, because of the scarceness of other faunas in the Upper
Jurassic of Moluccas, the faunal connection with the northern Pacific region
cannot be further ascertained.

(3) Australia and 3N-arc

In this region Jurassic pelecypod faunas are known in Upper Sepik of
New Guinea, west and central New Caledonia, Kawhia of north New Zealand,
Hokonui of south New Zealand and Western Australia.

In New Zealand the Jurassic pelecypod faunas are of primary importance
for stratigraphy, for ammonites seem comparatively rare except a few definite
horizons. The fauna, which was monographed by MARWICK (1953), is character-
ized by *Otapiria*, *Kalentera*, *Haastina* and some highly specialized groups be-
sides a considerable amount of Tethyan affinities. *Otapiria*, *Kalentera*, *Oxytoma*,
Entolium, *Pseudoaucella* and *Chlamys* occur in the Lias (TRECHMANN, 1923;
FLEMING, 1953; MARWICK, 1953), but the distribution of these species is now
confined to New Zealand and New Caledonia. The occurrence of *Sphaeriola*
already in lower Lias is probably a striking feature of the Pacific region,

since the genus is found also in the similar stages in western Japan and
Amur. Middle Jurassic faunas bear some Tethyan elements such as *Mele-
agrinella echinata* and *Camptonectes* cf. *laminatus*, but most other species
belonging to *Variamussium, Astarte, Kalentera, Tancredia, Homomya* and *Pleuro-
mya* are endemic. MARWICK referred some Bathonio-Callovian fossils to the
Spiti species described by STOLICZKA (1866) and HOLDHAUS (1913). The Upper
Jurassic fauna of New Zealand is composed of *Nuculopsis (Palaeonucula)*,
Nuculana, Grammatodon (Indogrammatodon), *Inoceramus, Otapiria, Aucella,
Pinna, Plagiostoma, Astarte* and *Haastina*. The resemblance of specific assem-
blage between the Upper Jurassic of Himalayas and this region is a striking
feature. Especially Oxfordian and later inoceramid faunas of New Zealand
and New Caledonia bear some common species with the Spiti shales such as
Inoceramus aff. *everesti* and *Aucella extensa*. Coarsely ribbed inoceramids such
as *Inoceramus galoi* and *I. haasti* flourished in the Oxfordian-Tithonian of
New Zealand and New Caledonia (ZITTEL, 1864; TRECHMANN, 1923; MARWICK,
1953; BARTRUM, 1937; ROUTHIER, 1953; AVIAS, 1953; MILLIGAN, 1959; FLEMING,
1959). Most of the inoceramids and associate *Aucella* occur also in the Upper
Jurassic of Moluccas. The Jurassic of Moluccas and 3N-arc is generally
represented by geosynclinal facies, and trigoniid- and cyrenoid-facies seem
undeveloped.

The Jurassic fauna of Australia seem to be composed of quite different
species from the 3N-arc region. MOORE (1870) described many species of
" Avicula ", " Pecten ", " Lima ", " Arca ", *Astarte* and *Cucullaea* from the " Oolite "
of Queensland and Western Australia, but their generic references should be
revised in future. According to TEICHERT (1939), two species of *Aucella* from
the Kimmeridgian of Western Australia are identical with Misol fauna.
Frenguelliella moorei is another common species between the Bajocian of Au-
stralia and Moluccas (WANDEL, 1936).

(4) Eastern Siberia (Lower Amur, Sichote Alins, Lower Lena and Olenek)

In eastern Siberia marine Jurassic pelecypods occur in lower Amur, Bureya
basin, Okhotsk, Sichote Alins, lower Lena and Olenek. In the Amur geosync-
line area the lower Lias is represented by neritic pelecypod facies with
Cardinia, Plagiostoma, Ctenostreon, Chlamys, Myoconcha and *Sphaeriola*. The
generic and even specific assemblages seem to me to be fairly similar to the
coeval Higashinagano fauna of western Japan (KIPARISOVA, 1952; HAYAMI,
1959i). Middle Liassic species seem comparatively rare except for some cos-
mopolitan species of *Plicatula* and *Oxytoma*. In Sichote Alins and Bureya area
of lower Amur, some species of *Inoceramus* occur in the Toarcian-Aalenian
(KIPARISOVA et al., 1958, 1960; KCHUDOLEY, 1959). The occurrence of *Ino-
ceramus eximius, I.* cf. *lucifer* and *I. ambiguus* suggests the faunal connection
with Alaska. *I. subambiguus* from the Aalenian of Okhotsk is quite similar
to *I. morii* of Northeast Japan. Bajocio-Bathonian pelecypods seem quite rare
in this region because of an extensive regression. LAHUSEN (1886) and
VORONETZ (1936) described *Inoceramus retrorsus, Solemya, Modiolus, Tancredia*
and some other thin-shelled pelecypods from the Lena and Olenek regions.

The inoceramid was reported also from the Bathonio-Callovian of Greenland (SPATH, 1932), and can be regarded as an element of boreal sea. *Inoceramus utanoensis* from the upper Toyora group of western Japan, which is a member of the group of *I. retrorsus*, seems to indicate the sea-connection with boreal province together with the *Seymourites*-fauna in the Callovian of central Japan (KOBAYASHI, 1947; HAYAMI, 1960c). According to KRIMHOLZ (1939) and others, *Modiolus* shales with *Modiolus*, *Meleagrinella* and some Callovian boreal ammonites occur in Bureya basin. Several species of "*Eumorphotis*" from the Middle-Upper Jurassic were lately denominated as *Arctotis*. Besides, *Bureiamya* was reported from the Callovio-Oxfordian of this region and *Aucellae* seem quite common in the Kimmeridgian and Volgian, though I could not refer to their original descriptions.

From the biogeographical point of view, it is recognized that the faunal connection between eastern Siberia and the Inner Zone of Southwest Japan was fairly intimate not only in the Triassic but also in many stages of the Jurassic period. In fact, many related species appear almost coevally both in the two regions as listed below:

	Eastern Siberia, Ural	Inner Zone of Southwest Japan and North Japan
Lower Jurassic	*Cardinia amurensis* KIPARISOVA	*Cardinia toriyamai* HAY.
	Sphaeriola sibirica KIP.	*Sphaeriola nipponica* HAY.
	Lima (Pl.) parapuncta KIP.	*Plagiostoma matsumotoi* HAY.
	Chlamys textoria (SCHLOTH.)	*Chlamys textoria* (SCHLOTH.)
	Oxytoma cygnipes var.	*Oxytoma* cf. *cygnipes*
Middle Jurassic	*Inoceramus subambiguus* PČELINCEVA	*Inoceramus morii* HAYAMI
	Inoceramus cf. *lucifer*	*Inoceramus* cf. *lucifer*
Upper Jurassic	*Inoceramus kystatymensis* KOSCHELKINA	*Inoceramus utanoensis* KOB.
	Solemya strigata LAHUSEN	*Solemya suprajurensis* HAY.
	Entolium nummulare (D'ORBIGNY)	*Entolium inequivalve* HAY.
	Lima consobrina D'ORBIGNY	*Limatula iwayae* HAYAMI
	Modiolus sibiricus BODYLEVSKY	*Modiolus maedae* HAYAMI
	Thracia cf. *lata* AGASSIZ	*Thracia shokawensis* HAY.
	Pholadomya uralensis D'ORBIGNY	*Tetorimya carinata* HAYAMI

The presence of a brackish fauna in the Upper Jurassic of Sichote Alins is very interesting for the consideration of palaeobiogeography and evolution of cyrenoid pelecypods, since cyrecoids is quite abundant also in the Upper Jurassic of the Inner Zone of Japan. But the discussion should be founded on firmer palaeontological basis. In the boreal province no striking faunal gap exists between the Upper Jurassic and Lower Cretaceous. One pelecypod species often occur both in the two epochs.

(5) North America (Alaska, Prince Patrick, British Columbia, Yukon, Alberta, Pacific coast and Western Interior of U.S.A.)

In Alaska VON EICHWALD (1871) described *Inoceramus* and many other

pelecypods as "Neocomian or Gault species", but MARTIN (1926) and many others regarded them as Jurassic species. MARTIN listed numerous pelecypods from the Lower, Middle and Upper Jurassic of Cook Inlet, Kenai peninsula, Malanuska, Talkeetna, Alaska range, Susitina valley, Chitina valley and Alaska peninsula, but the greater part of them is as yet undescribed. IMLAY (1955) regarded *Inoceramus lucifer* and *Aucella mosquensis* respectively as Bajocian and Kimmeridgian indices of north and south Alaska. *Aucella spitiensis*, an element of Spiti shales of Himalaya, occurs also in this region. Although the detailed comparison with Japanese fauna belongs to a future problem, it is now presumed that several pelecypods accompanied by *Tmetoceras* and *Stephanoceras* in the Aalenian and Bajocian Texedni formation may be allied to the faunas of the upper Shizukawa and lower Hashiura groups in Northeast Japan. Besides, ULRICH (1910) proposed *Inoceramya* for a transitional form between *Posidonia* and *Inoceramus* from the undated Mesozoic terrain of Yakutat area.

In Canada, Jurassic pelecypods are distributed widely in Prince Patrick, west Yukon, and various localities of British Columbia and Alberta (FREBOLD, 1953). FREBOLD (1957) described *Cucullaea*, *Protocardia* and *Pleuromya* from the Toarcian, and *Oxytoma* and *Goniomya* from the Bajocian of Prince Patrick. The lower Bajocian with *Oxytoma jacksoni* fauna is widespread in Melville, Mackenzie King and Axel Heiberg islands besides Prince Patrick (TOZER, 1960), and the species shows the presence of faunal connection with Cape Flora and Franz Joseph Land. *Inoceramus lucifer* is found also in Prince Patrick. LEES (1934) reported a Liassic fauna including *Gervillia*, *Trigonia*, *Modiolus*, *Pleuromya* and *Goniomya* from the Laberge area of Yukon, but the fauna is unknown in other places.

The pelecypod faunas in the Pacific coast of British Columbia were investigated by CRICKMAY (1928, 1930a, b). He described *Parallelodon* (including *Gilbertwhitea*), *Grammatodon*, *Modiolus*, *Gervillia*, *Entolium*, *Pinna*, *Gryphaea*, *Vaugonia*, *Myophorella* (*Haidaia*), *Astarte*, *Pleuromya* and many other pelecypods from the Middle Jurassic of the Harrison Lake and Ashcroft areas. Some of his newly established genera such as *Ashcroftia*, *Parapecten*, *Vaugonia* and *Haidaia* are important groups not only in British Columbia but also in various areas of the Pacific region. FREBOLD (1959) reported the occurrence of *Chlamys*, *Plagiostoma*, *Trigonia*, *Cardinia* and *Goniomya* from the Sinemurian and Bajocian of the Nelson-Salmo area. The fauna bears some European affinities, but *Cardinia* aff. *regularis* Terquem seems not much different from *C. toriyamai* from the lower Lias of west Japan. In Vancouver Island and Tyaughton Lake area *Aucella* occurs together with Oxfordian or later arctic ammonites.

In the Canadian Rocky mountains and the foothills the Jurassic is well represented by the characteristic Fernie shales. WARREN (1931), COLLET (1931) and FREBOLD (1957) reported some Sinemurian and Toarcian pelecypods comprising some cosmopolitan elements such as *Oxytoma cygnipes*, "*Lima*" *terquemi*, *Inoceramus* cf. *dubius*, *Lima* cf. *gigantea* and *Meleagrinella substriata*. MC-

LEARN (1924), WARREN (1932) FREBOLD (1957) described many pelecypods from the Bajocian and Callovian of the Fernie shales in Alberta. The faunas are composed of *Cucullaea, Oxytoma, Inoceramus, Camptonectes, Entolium, Plagiostoma, Gryphaea, Trigonia, Protocardia, Arctica, Pleuromya* and *Corbula*. These genera can be commonly found in the Jurassic of many other areas, but the specific assemblage is quite different from either of Europe-Tethys and western and southern Pacific regions. The characteristic occurrence of *Gryphaea impressimarginata* and *Corbula munda* at the Bathonian-Callovian passage remind at a glance one of *Eligmus-Gryphaea* fauna of the Ethiopian province, but the constituent species seems quite different from each other. Oxfordian *Ancella* is found also in Fernie shales together with cardioceratids.

In the Pacific coast of the United States Jurassic pelecypods are known in east-central Oregon, north and central California and west Nevada. GABB (1870), HYATT (1894) and CRICKMAY (1933) described *Pinna, Entolium, Parapecten,* etc. from the Lower and lower Middle Jurassic of Mt Jura area. MULLER and FERGUSON (1939) listed some Liassic pelecypods from Hawthorne-Tonopar area of western Nevada, and pointed out that CRICKMAY's *Parapecten* appear to be nothing but the famous South American Liassic species, *Weyla alata* (BUCH). Besides, *Myophorella, Vaugonia, Entolium, Pholadomya, Chlamys* and *Goniomya* occur in the lower-middle Lias, and some of them were lately described by SANBORN (1960).

PACKARD (1921) monographed the trigoniids of California and some other areas of Pacific coast, and many generic names were given them by CRICKMAY (1932). In accordance with recent trigonian studies accomplished by COX (1951) and KOBAYASHI, MORI and TAMURA (1954–1959), *Trigonia, Vaugonia, Myophorella, M. (Haidaia), M. (Promyophorella)* seem to occur in this region. The generic assemblage is more similar to the normal Jurassic trigoniid faunas of Japan than Europe and India.

The Tithonian fauna of the Knoxville beds, which STANTON (1896) regarded as Lower Cretaceous, includes *Nucula, Oxytoma, Aucella, Inoceramus,* "*Pecten*", *Astarte, Opis, Lucina* and *Corbula. Cardiniopsis* is characteristic of the Knoxville. GILLET (1924) regarded the fauna as a member of boreal province (north-andine subprovince), and the abundant *Aucella* may constitute an element of northern sea. The ammonites of the Callovian-Kimmeridgian of Sierra Nevada are also of boreal type, but the Knoxville ammonites appear in part to show the connection with Mexican province. The Franciscan group of the Coastal Range is at least in part Lower Cretaceous (SCHLOCKER et. al., 1954), but some Tithonian (?) pelecypods including *Aucella piochii* occur in the group in south California (EASTON and IMLAY, 1955).

In the Western Interior Jurassic pelecypods are known from the Bajocian, Callovian and Oxfordian of the Sundance inland sea facies and Kimmeridgian-Tithonian non-marine Morrison formation in Utah, Wyoming and some other states (IMLAY, 1952, etc.). MEEK (1877, etc.) STANTON (1899), WHITFIELD and HOVEY (1906) and CRICKMAY (1936) descibed some marine pelecypods such as *Cucullaea, Modiolus, Gervillia, Meleagrinella, Camptonectes, Ostrea, Gryphaea,*

Trigonia, Astarte, Pholadomya, Pleuromya, Thracia and *Cercomya* chiefly from the Bajocian and Callovian of Wyoming. It is noticeable that few pelecypod species range from Callovian into Oxfordian, and that a certain faunal change took place at the regressive period. The generic assemblage is not much different from normal Middle-Upper Jurassic faunas of other regions, but most constituent species are endemic in the inland sea. IMLAY (1957) discussed the palaeoecology of the Sundance sea, making clear the relation between the fossil assemblage and lithology. "*Astarte, Trigonia, Pleuromya, Grammatodon* and *Pinna* were adapted to a considerable range of environment, as they lived on sandy, shaly and limy bottoms. *Mytilus* is commonly associate with *Ostrea* in shallow sandy deposits but not with *Gryphaea*. On less sandy limy bottoms lived such forms as *Cucullaea, Nucula, Ctenostreon, Oxytoma, Plagiostoma, Gryphaea, Ostrea, Lopha, Gervillia, Volsella, Pholadomya, Panope, Homomya, Goniomya, Cercomya, Pleuromya, Protocardia* and *Inoceramus*. On softer muddy bottoms lived *Isocyprina, Thracia, Pleuromya, Pholadomya, Panope, Astarte, Trigonia* and *Pinna, Opis* and *Corbis* occur in the Middle Jurassic dolomites and limestones with gypsum and red beds." Such tendencies may or may not agree with the bio-facies in the Jurassic of Japan which I described already. A comprehensive study on the genus *Aucella*, which ranges from upper Oxfordian to Valanginian in North America, was accomplished by IMLAY (1959).

The non-marine Morrison formation of Wyoming, Utah and Colorado yields many species of unionids (MEEK and HAYDEN, 1858; WHITE, 1886; LOGAN, 1900; HENDERSON, 1935; BRANSON, 1935; YEN and REESIDE, 1946, 1950).

(6) Mexico and Gulf Coast

FELIX (1894) reported some *Exogyra* and *Gryphaea* from the Upper Jurassic of the Oaxaca area of south Mexico. CASTILLO and AGUILERA (1895) described many pelecypods from the Sierra de Catorce in San Luis Potosi of Mexico. The work was carefully revised by IMLAY (1940), and is known that the Mexican Upper Jurassic fauna is well characterized by the prolific occurrence of *Grammatodon* (probably *Indogrammatodon*), some characteristic trigoniids, *Aulacomyella, Meleagrinella, Astarte, Arctica* and (?) *Solenomorpha*. The distribution of the fauna is now confined to the coastal deposits of the Mexican geosyncline in Mexico and Gulf Coast, and the generic assemblage and associate ammonite seem more intimate to Tethyan faunas than those of the Pacific coast and the Western Interior. *Aulacomyella* is said to have been recorded only from middle Kimmeridgian.

In the Malone area of western Texas is displayed a splendid neritic calcareous formations with rich Upper Jurassic pelecypods. CRAGIN (1905) described many species of *Gryphaea, Exogyra, Lima, Plicatula, Ctenostroen, Camptonectes, Gervillia, Mytilus, Modiolus, Pinna, Cucullaea, Astarte, Ptychomya, Lucina, Arctica, Pholadomya, Pleuromya, Anatina* and *Martesia*. Many species are common with the Mexican Upper Jurassic faunas, and a few are allied to South American ones. There are a few intimate forms with the Knoxville beds of California, but no species is common with the Western Interior. The appearance of *Steinmannella* and *Apiotrigonia* seem somewhat earlier than

western Pacific. Many elements of the Mexican and Malone faunas are known in the Cotton Valley formation and Smackover limestone which belong to the deeply buried Jurassic of Arkansas, Alabama, Louisiana and eastern Texas (IMLAY, 1941, 1945). The Smackover fauna is said to bear several European affinities.

Lower and Middle Jurassic pelecypods are undescribed in this region except a few species of *Chlamys*, *Plagiostoma*, *Lopha*, *Trigonia*, *Astarte* and *Myoconcha* from the Lias of Sonora. Some species were compared with European species, and there are several South American elements (JAWORSKI, 1929).

(7) South America (Peru, Chile, Mendoza, Neuquen, Patagonia)

The distribution of Jurassic pelecypods in South America is almost confined to the middle and southern part of the Andine geosynclinal area, namely Peru, Bolivia, north Chile, Mendoza, Neuquén and Patagonia. The assemblage of pelecypods of these areas are very similar to one another, and this region constitutes a distinct faunal province from other regions of Pacific. However, I am rather astonished to find that so many names of famous European species have been given to South American pelecypods, though some of them certainly should be separated from typical forms.

The Liassic faunas of this region are well characterized by the prolific occurrence of *Weyla alata* (BUCH) or its allied pectinids, *Gryphaea* (mainly *G. darwini*), *Freguelliella*, *Vaugonia* and *Cardinia* (mainly *densistriata*-subgroup in my classification, 1958e) (BAYLE and COQUAND, 1850; MORICKE, 1894; TILMANN, 1917; JAWORSKI, 1913, 1916, 1926a, b; WEAVER, 1931; FERUGLIO, 1934; LEANZA, 1942). Other constituent genera are *Nucula*, "*Cucullaea*" (mostly *Grammatodon*), *Modiolus*, *Isognomon*, *Inoceramus* (probably *Parainoceramus*), *Gervillia*, *Oxytoma*, *Lopha*, *Gryphaea*, *Chlamys*, *Entolium*, *Variamussium*, *Plagiostoma*, *Ctenosteon*, *Myoconcha*, *Astarte*, *Lucina*, *Arcomya*, *Homomya*, *Pleuromya* and *Pholadomya*. The assemblage reminds at a glance one of normal European Liassic faunas. In fact, "*Arca*" *rhomboidalis*, *Oxytoma inequivalvis*, *Chlamys textoria*, *Entolium disciforme*, *Eopecten valatus*, *Arcomya elongata*, *Pholadomya hemicardia*, *Pleuromya striatula* and many other species from Neuquén indicate intimate faunal connection with Europe. But some of them, especially the pectinids, are known also in Japan and southeastern Asia and regarded as cosmopolitan elements. As I noted before (1957d), *Camptonectes lens* by LEANZA (1942) resembles *Radulonectites* which is found in the Lias of Central Japan.

Middle Jurassic pelecypods seem also very common in this region especially in the Bajocian at Espinazito pass of Argentina (GOTTSCHE, 1878; TORNQUIST, 1898; BURCKHARDT, 1903; JAWORSKI, 1926; WEAVER, 1931). *Nuculana*, *Cucullaea*, *Modiolus*, *Oxytoma*, *Meleagrinella*, *Posidonia*, *Camptonectes*. *Entolium*, *Trigonia*, *Jaworskiella*, *Frenguelliella*. *Vaugonia* (s. s. and *Hijitrigonia*) *Myophorella*, *Cardiniopsis*, *Astarte*, *Protocardia*, *Sowerbya*, *Gresslya*, *Pleuromya* and *Pholadomya* are well represented in this part. Many species range from Upper Lias into Bajocian. *Modiolus imbricata*, *Oxytoma münsteri*, *O. costata*, *Meleagrinella substriata*, *M. echinata*, *Camptonectes laminatus*, *Entolium disciforme*, *Gryphaea calceola*, *G. subobata*, *Pleuromya jurassi*, *Pholadomya fidicula* and many

other forms are said to be identical with the Middle Jurassic faunas of Europe. According to JAWORSKI (1926) an allied species to *Inoceramus galoi,* an element of Moluccas and 3N-arc, occurs in the same stage. All the trigoniids of Neuquén monographed by LAMBERT (1944) are endemic species in South America. *Trigonia, Frenguelliella* and *Vaugonia* are well represented by many species at various horizons until Upper Jurassic. PHILLIPI (1899) described trigoniids and many other fossils from the Jurassic of Chile, and the fauna is said to be mostly composed of endemic species.

Upper Jurassic pelecypods are known also in Neuquén and some other areas (HAUPT, 1907; WEAVER, 1931; DIAZ, 1959), but the constituent species are much smaller in number. *Gervillia, Gryphaea, Trigonia, Ctenostreon, Modiolus, Pleuromya, Pholadomya, Astarte* and *Lucina* occur in the Callovian, and *Aucella,* "*Ostrea*", *Entolium, Apiotrigonia, Myophorella, Astarte, Lucina* and *Pholadomya* in the Tithonian.

The Jurassic faunas of Caracoles area of in the frontier between Chile and Bolivia described by STEINMANN (1881) have similar specific assemblages to those of Neuquén. *Posidonia* seems especially common in the Middle Jurassic.

V. Evolution of Jurassic Pelecypods

To my regret, the Jurassic pelecypod specimens in Japan and its adjacent territories are often worse than European ones in the state of preservation. Nevertheless, I perceive that the evolution of Mesozoic pelecypods seems fairly different in many respects between Pacific and European regions. Therefore, it leaves much room for improvement upon the concept about the evolution of Mesozoic pelecypods which is generally founded on the evidences in Europe. There are many common genera and subgenera between the two regions, but some appeared much earlier in one region than the other. My special attention has been paid on the faunas of the Pacific region, since Japan belongs to the circum-Pacific orogenic belt and the region seems lagging behind the European and Tethyan regions in the palaeontology. It can be readily imagined that some peculiar physico-chemical conditions, which were absent in Europe, were produced in the Pacific region by the strong Mesozoic orogenic disturbances. It seems an interesting problem to recognize how the different conditions have influenced on the generic and specific assemblages and pelecypod evolution.

In this article are treated the stratigraphical and geographical distributions of some pelecypod groups which are more or less commonly found in the Indo-Pacific region. Presumable general trends of evolution, if ascertained from the morphological transformation and stratigraphical occurrence, are also noted in some detail. Jurassic pelecypod faunas are generally much different from Triassic ones in the generic assemblage. In fact, some genera appeared at first in lower Lias and some other stages of Jurassic. But some other genera, which have been said in many text-books to have appeared at first in Lias,

are actually represented by a few species already in Upper Triassic. In north-western Europe Rhaetic (or Infraliassic) transgression took place on the Upper Triassic non-marine terrains, and many pelecypod genera apparently evolved since the stage. In view of the stratigraphical distribution of Triassic and Jurassic species of the world, however, the faunal change must be said to be fairly gradual.

The stratigraphical and geographical distribution of Jurassic pelecypods belonging to more or less common genera in the Indo-Pacific regions are sum-merized in the following tables. In this occasion I emend the generic refe-rences of some species in the Pacific region in accordance to modern pelecypod classification. Each vertical column does not mean phylogenetical relationship, and each species has a certain vertical range. But the material seems not enough to establish reliable genealogical trees and detailed range charts. Comparable European species are also tabulated in the left columns.

(1) Solemyacidae appeared already in Silurian, and *Solemya* was seemingly persistent during whole Mesozoic times without any striking morphological transformation. It probably adapted to calm muddy bottom of neritic to con-siderable depth, and made a bare living until Recent. Some of Jurassic *Solemya* seem to have *Acharax*-like ligament position, but in most cases the ignorance of ligament prevents me from determining the subgeneric references.

(2) Ctenodontidae are a primitive palaeotaxodont family ranging from Devonian (or earlier) to Jurassic. Mesozoic *Palaeoneilo* is probably a terminal group of the family. In Cutch *Palaeoneilo belaensis* and *P. indicus* seem common respectively in the Bathonian and Oxfordian, but their trace to the Pacific region is as yet unknown.

(3) Nuculidae are fairly common in various Jurassic stages of Indo-Pacific

Table 9.

NUCULOPSIS (PALAEONUCULA)

	Europe	India	Indonesia	3N-arc	Japan	Mexico	S. America
Upper Jurassic	menkii subhammeri	spitiensis hyomorpha cf.menkii stoliczkai blanfordi kaoraensis	taliabutica	truncata	makitoensis	antiqua	
Middle Jurassic	waltoni variabilis hammeri	cuneiformis	hammeri cf.eudorae				leufuensis
Lower Jurassic	hausmanni		ovum cf.hausmanni subserradensis subovalis		sp.		patagonidica

Table 10.

NUCULANA (DACRYOMYA) & N.(PRAESACCELLA)   * Nuculana (Praesaccella)

	Europe	India	3N-arc	Japan	S. America
Upper Jurassic		juriana*	australis	yatsushiroensis* stenodolichos minutula erinoensis*	
Middle Jurassic	lacryma	lacryma			striatissima
Lower Jurassic	doris complanata graphica tenuistriata texturata		vexillata	toriyamae	acuta acuminata

Table 11.

PARALLELODON   * Parallelodon (Torinosucatella)

	Europe	India	3N-arc	Japan	N. America
Upper Jurassic	keyserlingii	lerensis	"egertonianum"	kobayashii* kesennumensis inflatus koikensis	taffii cardioceratanus
Middle Jurassic	bynei rudis hirsonensis rugosus			sp.	micromorpha
Lower Jurassic	daharensis buckmanni			sp. infraliassicus niranohamensis	

regions, and most species of the family with entire ventral margins, I think, belong to *Nuculopsis* (*Palaeonucula*) which is persistent from Triassic and probably ancestral to Cretaceous *Leionucula*. *N.* (*P.*) cf. *hausmanni* and allied forms are known in the Lias of Moluccas, Timor and (?) South America. Many cuneiform species of *Palaeonucula* allied to *N.* (*P.*) *hammeri* appeared in

the Bathonian-Tithonian of Cutch and Spiti, and their trace into Pacific is known in the Middle Jurassic of Miso�¹.

(4). Nuculanidae are also common in the Jurassic of Indo-Pacific regions and generally classified into *Nuculana (Dacryomya)*, *N. (Praesaccella)* and *Rollieria*. *Dacryomya* occurs in Japan, New Zealand and Mendoza besides India. It seems a general tendency for Liassic species to have less prominent umbo and more elongated posterior rostrum than Upper Jurassic ones. It is highly probable that such Liassic species belong to the group called " *Ryderia* " by some authors and that true *Dacryomya* appeared at first in the Middle Jurassic or later in the Pacific region.

(5) Parallelodontidae are not very common except for certain horizons of limited area. Though *Parallelodon* is an important member of Jurassic faunas in Japan, only some sporadical occurrences were announced in the Upper Jurassic of India and Canada. No definite species was so far reported from boreal and south Pacific regions. *Parallelodon* itself ranges from Devonian to Jurassic, and the Uppermost Jurassic species appear terminal. In fact, some deviated forms from typical *Parallelodon* appear in the Upper Jurassic of Japan, for instances, *P. kesennumensis* and *P. (Torinosucatella) kobayashii*. A similar form to *Torinosucatella* is known in the Lias of Sweden (TROEDSSON, 1951), but it is a question whether there was a persistent stock of the subgenus during the Jurassic period or not.

Table 12.

GRAMMATODON   * Grammatodon (Indogrammatodon)

	Europe	India	3N-arc	Japan	N. America	Mexico	S. America
Upper Jurassic	alsaticus concinnus	egertonianus* iddurghurensis* kantkotensis* jurianus virgatus*	fyfei* sparsilineatus* taylori*	takiensis densistriatus*		cassilineatus* delicatulus* reticulatus*	
Middle Jurassic	bathonicus	sp. andhouensis			ornatus sonninianus semiornatus ferniensis		
Lower Jurassic	inequivalvis*		inequivalvis*	sp. toyorensis nakanoi*			

(6) Cucullaeidae first appeared in Upper Triassic, and flourished world-widely in Jurassic and Cretaceous. The differentiation of *Grammatodon* (s. s.), *G. (Indogrammatodon)* and *Cucullaea* (s. l.) from *Parallelodon* occurred already by the beginning of Jurassic, because each group can be found in the lower Lias of Japan and some other areas. Liassic species such as *G. inequivalvis*

and *G. nakanoi* are relatively small in size and probably early representatives of *Indogrammatodon*. Upper Jurassic *Indogrammatodon* with large dimensions and characteristic ornamentation is common not only in Cutch and Spiti but also in Japan, 3N-arc, Mexico and Gulf Coast. *Grammatodon toyorensis* from the lower Lias of Japan, *G. andhouensis* from the Bathonian of Cutch and *G. takiensis* from the Upper Jurassic of Japan are very similar to one another, and a persistent trunk of *Grammatodon* (s. s.) is suggested to exist also in the Indo-Pacific regions. *Grammatodon* is found also in Neuquén, Canada and Western Interior, but its scarceness in the boreal region including Siberia and Alaska is a remarkable fact. Typical species of *Cucullaea* are probably did not yet appear in the Jurassic. Many Jurassic species described under the generic name of *Cucullaea* are at least subgenerically separable from *Cucullaea* (s. s.). Middle Jurassic species including *Ashcroftia* from Canada seem especially common in the northern Pacific and South America. *Megacucullaea* appeared in the Upper Jurassic of Indian region and survived into Lower Cretaceous.

Table 13.

MODIOLUS   * Modiolus (Inoperna)

	Europe	India	Indonesia	Japan	E.Siberia	N.America Mexico	S.America
Upper Jurassic	perplicatus* plicatus* bipartitus	plicatus* glendayi cf.bipartitus		cf.bipartitus plicatus* maedae	solenoides	geniculata malonianus subimbricatus rosii frankensis	
Middle Jurassic	imbricatus sowerbyanus* plicatus* solenoides giganteus imbricatus cuneatus plicatus*	imbricatus patchamensis* cf.angustissimus cuneatus imbricatus	cf.scalatus	sp.*		sphenoproratus abbreviatus	cf.giganteus cuneatus imbricatus
Lower Jurassic	scalatus scalprus hillanus			sp. bakevelloides		scalprus mandannaensis	gigantoides hillanus mollensis scalprus

(7) Mytilidae ranging from Devonian to Recent flourished in the Jurassic, and various groups were differentiated from persistent trunk of *Modiolus* in this period. *Modiolus imbricatus* and *M. cuneatus* flourished world-widely in the Middle Jurassic. *M. bipartitus* and its allied forms occur in the Upper Jurassic of Europe, India and Japan. *M. maedae* from the Oxfordian (?) of inner Japan is probably intimate with certain Russian species such as *M. sibiricus* and *M. turkestanicus*. Subgenus *Inoperna* is a well defined group in Middle-Upper Jurassic and Cretaceous, and it has been said to have been derived from certain Liassic ensiform species of *Modiolus*. *M.* (*Inoperna*) *plicatus* shows a wide distribution in the Upper Jurassic of Tethys and Japan. But

Jurassic species of *Inoperna* seem rare in other regions of Pacific, though Cretaceous species are well represented in North America. Most Jurassic mytilids without radial ribs, umbonal septum and anterior wing may belong to *Mytilus (Falcimytilus)*. *Falcimytilus* was probably branched from *Modiolus* in the Upper Triassic and Lower Jurassic, and its derivation is suggested by many intermediate species in the Jurassic of various regions. *Lycettia* is known in the Middle and Upper Jurassic os Tethyan regions but unknown in the Pacific. *Arcomytilus* seems also rare, but some primitive (?) species occur in the Lias of Japan, and typical species such as *A. laitmairensis* in the Upper Jurassic of Tethys, Japan and Mexico.

(8) Pteriidae are said to have appeared already in Devonian, and many Jurassic species were described from the Pacific region as *Pteria* (or *Avicula*), though some of them are surely referable to the Aviculopectinidae. *Pteroperna* seems to have flourished in the Middle and Upper Jurassic of India, Borneo, Japan and Mexico, but probably is unknown in boreal province. Typical *Pteria* appeared probably at first in the Upper Jurassic, and is found in the calcareous deposits of Japan as well as European Corallian.

(9) Aviculopectinidae flourished chiefly in Upper Palaeozoic and Triassic, and represented by *Oxytoma* and *Meleagrinella* in Jurassic and Cretaceous. *Oxytoma* appeared at first in the Rhaetic in Europe, but in eastern Asia typical representatives with large dimensions flourished already in the Carnic. *O. cygnipes* or allied forms with small number of primary radials show cosmopolitan distribution in lower and middle Lias. *O. inequivalvis* mainly from the Lower Jurassic and *O. münsteri* from the Middle-Upper Jurassic are also cosmopolitan, and form a main trunk of *Oxytoma* during the Jurassic period. Such a species can be found in various areas of Pacific region except for North America where *O. jacksoni* shows extensive distribution in Middle Jurassic

Table 14.

MELEAGRINELLA   *Arctotis

	Europe	India	3N-arc	Japan	E. Siberia	Mexico	S. America
Upper Jurassic	laevis ovalis				echinata lenaensis*	durangensis louisianensis tamaulipana	
Middle Jurassic	echinata	echinata	echinata sinuata		intermedia*		echinata substriata
Lower Jurassic	substriata papyria			sp. sp. japonica			cf.papyria

Table 15.

OXYTOMA

	Europe	India	Indonesia	3N-arc	Japan	N. America	S. America
Upper Jurassic	münsteri	münsteri	münsteri		tetoriensis	wyomingensis blairmorensis	
Middle Jurassic	expansa costata münsteri		cf.münsteri	sp.	cf.münsteri	submcconnelli mclearni jacksoni	costata münsteri
Lower Jurassic	inequivalvis cygnipes scanica		inequivalvis	sp. sp.	septentrionalis sp. inequivalvis cf.cygnipes	cygnipes	inequivalvis

Table 16.

AUCELLA   * Pseudaucella

	Europe	India	Indonesia	3N-arc	E. Siberia	N. America
Upper Jurassic	lahuseni pallasi lindstroemi mosquensis bronni	spitiensis leguminosa blanfordiana	plicata misolica malayomaorica motlolensis subspitiensis	extensa plicata malayomaorica subpallasi subspitiensis boehmi	mosquensis pallasi lindstroemi ochotica piochei bronni	fischeriana piochii rugosa mosquensis concentrica spitiensis
Middle Jurassic					subbronni minima	
Lower Jurassic				marshalli*		

times. *Meleagrinella* (=*Echinotis*) typified by *M. echinata* is also common in Indo-Pacific regions. Many species hitherto described as *Pseudomonotis* from the Lower-Middle Jurassic of South America and Upper Jurassic of Mexico belong to this genus. In the boreal region *Meleagrinella* appears comparatively rare, but several species with large dimensions and comparatively weak convexity of left valve such as *"Pseudomonotis" lenaensis*, for which BODYLEVSKI (1960) proposed *Arctotis*, seem to be related to *Meleagrinella*.

(10) Aucellidae flourished in Upper Jurassic and Lower Cretaceous. It had

been said that *Aucella* is characteristic of the boreal province, but typical species are common also in deep facies of Himalayas, Moluccas, New Zealand and ? South America besides eastern Siberia, North America and Europe. In North America, especially boreal province, *Aucella* flourished sinch upper Oxfordian until Lower Cretaceous, and several zones have been recognized in Alaska, Oregon and California by means of the assemblage of species. In Himalaya, Moluccas and New Zealand several species of *Aucella* are represented in the Upper Jurassic shaly formations, but in Japan and many other areas of Pacific I have not heard the occurrence of the genus. *Pseudoaucella* is characteristic in the Lias of 3N-arc region, but the phyletic relationship between the two genera is unknown. Many authors consider *Aucella* to have been derived from the Aviculopectinidae such as *Meleagrinella* (POMPECKJ, 1901; IMLAY, 1959).

(11) Posidoniidae ranges from Carboniferous to Jurassic. Jurassic *Posidonia* is generally smaller than earlier species. *P. ornati* or its allies show cosmopolitan distribution in Middle-Upper Jurassic. *P. bronni* from the Lias of Europe and South America is said to have multivincular ligament structure and some authors distinguish it as *Steinmannia* (or *Aulacomya*) from typical *Posidonia*. If it is phyletically related to *Inoceramya* from the Unknown Mesozoic group of South Alaska, they may be ancestral to some Middle Jurassic or later inoceramids.

(12) Halobiidae were derived from *Posidonia* in Triassic, and much declined after Rhaetic. However, *Amonotis*, *Posidonotis* and *Aulacomyella* occur respectively in the Lower, Middle and Upper Jurassic of Tethys, Japan and Mexico. These genera have usually narrow stratigraphical range and wide geographical distribution just as Upper Cretaceous descendant genus *Didymotis*.

Table 17.

GERVILLIA

* Gervillia (Cultriopsis) ** Gervillella
+ Bakevellia ++ Gervillaria

	Europe	India	Indonesia	Japan	N.America	S.America
Upper Jurassic	aviculoides** siliqua**	anceps** kantkotensis** siliqua**	borneensis	sp. takiensis tatenosawensis	cinderella corrugata+ montanaensis+ ferrieri dolabrata	leufuensis++
Middle Jurassic	waltoni+ acuta** ovata** northamptonensis* dundriensis*	waltoni+	cf.sulcata		ashcroftensis	cf.oblonga
Lower Jurassic			cf.lanceolata	magnissima+ negoyensis+ otariensis+ cassianelloides+ ohishiensis+ shizukawensis* trigona+		pallas cf.lamellosa

Though their phylogenetical relationship is not very clear, the intermittent occurrences of this family in the Jurassic and Cretaceous offer exceptional attractions to Mesozoic stratigraphers and conchologists.

(13) Bakevelliidae are a common group in many Jurassic faunas of Indo-Pacific regions, but their specific assemblage and evolution seem much localized. *Bakevellia* flourished especially in the embayment facies of Japanese Lias, and often attains large size in comparison with Permian and Triassic species. The distribution of *B. waltoni* is traceable in the Bathonian from Europe to Cutch, and some pteriform " *Gervillia* " from the Upper Jurassic of Mexican region may be referable to the genus. In South America " *Gervillia* " *leufuensis* appeared in the Callovian prior to *Gervillaria alaeformis* and its allies which flourished world-widely in Lower Cretaceous. It can be generally considered that Lower and Middle Jurassic *Gervillia* (*Cultriopsis*) is ancestral to Upper Jurassic and later *Gervillia* (s. s.). The stratigraphical occurrence of the two groups in the Pacific region agrees well with the fact in Europe. *Gervillella*, which may have been derived from *Bakevellia* in the Upper Triassic or Lower Jurassic, is common in the Middle-Upper Jurassic or Europe and India but scarcely found in the Pacific region. *Cuneigervillia* is more or less common in the Lias of Europe, but unknown in Indo-Pacific.

Table 18.

ISOGNOMON

* Isognomon (Mytiloperna)
** Gervilleioperna

	Europe	India	Indonesia 3N-arc	Japan	N.America	S.America
Upper Jurassic	subplanus mytiloides		giganteus cf.subplanus			bayani americanus*
Middle Jurassic	mytiliformis* isognomonoides bathonicus* rugosus	patchamensis*		cf.rikuzenicus	weelaupensis	isognomonoides
Lower Jurassic	isognomonoides		timorensis**	ageroensis* sp. rikuzenicus		

(14) Isognomonidae appeared at first in Middle Permian. Although Triassic species of this family are scarce but for a few species of *Waagenoperna* (=*Edentula*), a persistent trunk, which is independent from that of the Bak-evelliidae, can be expected through Triassic. *Isognomon* flourished in the Lower and Middle Jurassic embayment condition of Japan, and appeared again in the Lower Cretaceous without striking morphological change. Jurassic *Isognomon* is usually equivalve and thick and frequently attains large size,

Table 19.

INOCERAMUS   * Parainoceramus

	Europe	India	Indonesia	3N-arc	Japan	E. Siberia	N. America	S. America
Upper Jurassic	nitescens inoceramoides	stoliczkai gracilis everesti sularum sp.	haasti subhaasti sularum taliabuticus galoi	haasti galoi	furukawensis maedae cf.nitescens hamadae ogurai	retrorsus	obliquiformis	ex gr.galoi
Middle Jurassic	fittoni polyplocus fuscus			inconditus brownei	utanoensis cf.galoi hashiurensis karakuwensis cf.lucifer morii	kystatymensis menneri	ambiguus ferniensis lucifer	
Lower Jurassic	dubius* substriatus* pernoides*				cf.fuscus kudoi matsumotoi* lunaris*	lucifer subambiguus ussuriensis	dubius*	dubius* apollo*

while Recent species often have inequivalve, irregular outlines and comparatively thin tests. Subgenus *Mytiloperna* is found in the upper Lias of Japan, Bathonian of Cutch and Upper Jurassic of South America. *Gervilleioperna*, which seems at a glance intermediate between *Bakevellia* and *Isognomon*, appeared coevally in the middle Lias of Timor and north Africa.

(15) Inoceramidae probably appeared at first in Upper Triassic, but their world-wide distribution is found after Hettangian. As I have discussed before (1960c), there are some general tendencies as to the morphological transformation of this family during Jurassic period. Small Liassic species often have *Bakevellia*-like dentition and are mostly referable to *Parainoceramus*. Middle and Upper Liassic species of *Parainoceramus* spread not only in Europe and western Tethys but also in Japan, Canada and South America. They may be the collateral ancestors to the group of *Inoceramus fuscus* with mytiliform or rhomboidal outline, which is commonly found in the Aalenian-Oxfordian of Europe, Caucasus and Japan. The group of *Inoceramus lucifer* with elongate outline and strong constrictions is found characteristically in the Bajocian of Alaska, Prince Patrick, eastern Siberia and north Japan. The group of *Inoceramus retrorsus* with more or less developed posterior wing, small apical angle and irregular concentrics may be also boreal, and flourished in the Bathonian-Callovian of Greenland, Siberia and western Japan. The group of *Inoceramus polyplocus* (i. e. subgenus *Mytiloceramus*) with orbicular outline appeared nearly coevally in the Bajocian of Europe and Japan. The group may have been derived from *Posidonia*-like shells, as noted above. On the other hand, the group of *Inoceramus galoi*, characterized by the regular coarse ribbing, developed in the Callovian-Tithonian of Himalayas, Moluccas and 3N-arc. In the Uppermost Jurassic *Anopaea* with non-terminal umbo and more or less

characteristic "lunule" associates with *Inoceramus* in European Russia, New Zealand and (?) Himalayas. *Inoceramus maedae* from the (?) Oxfordian of inner Japan has an unusually prominent umbo and highly inequivalve shells for Jurassic species, and seems to belong to the group of *Inoceramus neocomiensis* which flourished properly in Lower Cretaceous. The evolution of inoceramids seems thus fairly rapid in comparison with other pelecypod groups. Similar species appeared often coevally in far distant areas, though certain species groups show somewhat local development.

(16) Vulsellidae appeared in Jurassic, and it is known that Recent species (and probably fossil species) live commensally with sponges. *Eligmus* ranging from Bajocian to Callovian flourished especially in the Tethyan region. *E. rollandi* or its allied forms show wide distribution in the Bathonian of east Africa, Madagascar, Turkey, Cutch and Upper Burma. Bathonian deposits are comparatively rare in the Pacific region, but it may bear something on palaeobiogeography and pelecypod evolution that no specimen of the genus has ever been found therefrom.

(17) Pinnidae are said to be persistent from Palaeozoic and derived from certain group of the Pteriidae. The extensive development of *Pinna* is, however, found at first in the Middle Jurassic. Many of Jurassic species in the Indo-Pacific regions have a distinct median parting and fine radial striations on the surface. *Pinna mitis* or its allied forms are distributed in the Upper Jurassic of Europe, India and Japan. *Trichites* is found in the Upper Jurassic of Cutch but probably unknown in the Pacific.

(18) Pectinidae flourished world-widely in the Triassic and later periods. Undoubted *Chlamys* exists already in the Carnic of Japan and eastern Siberia. *Chlamys textoria* is a cosmopolitan Liassic species, and constitutes one of main

Table 20.

CHLAMYS   * "Aequipecten"

	Europe	India	Indonesia	Japan	E. Siberia	N. America	S. America
Upper Jurassic	splendens	subtextoria cf.episcopalis		iboibo vulgaris* camptonectoides mitaraiensis sp.		mcconnelli	
Middle Jurassic	ambigua subtextoria viminea dewalquei	ambigua curvivarians		kobayashii		pardeios	
Lower Jurassic	textoria		textoria	kurumensis kotakiensis textoria toyorensis*	textoria	textoria	textoria priscus*

stocks of the genus in each region. *Textoria* and most other Liassic *Chlamys* have comparatively flattenend right valves, but Middle Jurassic and later *Chlamys* is generally equivalve except for the byssal part. *Chlamys mitaraiensis* from the Upper Jurassic of Inner Japan, having *Camptochlamys*-like lattice ornamentation, is probably phyletically related to some boreal *Chlamys* instead of *Camptochlamys*. "*Aequipecten*" which I -use for the group of "*Pecten*" *priscus*, is common in various Jurassic stages of Indo-Pacific regions as well as Europe. *Radulopecten* is probably a Tethyan element, and its distribution seems to be confined properly to western Europe, Africa, India, (?) Mindoro and outer Japan. *Pseudopecten, Spondylopecten, Plesiopecten* are unknown in Pacific. "*Pecten*,, *alata* its allied well inflated forms occur commonly in the Lias of South America. They seem most intimate to modern *Pecten* (s. s.) among various Jurassic scallops and may be ancestral to it. *Parapecten ntlakapamuxanus, P. praecursor* and *P. acutiplicatus* from the Pacific coast of North America are probably related to the South American species, but such a pectinid is unknown in the western Pacific region.

Table 21.

CAMPTONECTES   * Camptonectes (s. l.)

	Europe	India	Indonesia	3N-arc	Japan	E. Siberia	N. America	S. America
Upper Jurassic	auritus	indicus auritus		grandis*	aff. browni mimikirensis* torinosuensis* sp.		bellistriatus pertenuistriatus platessiformis	
Middle Jurassic	auritus laminatus	luchiangensis laminatus cf.arcuatus cf.browni	aalensis	cf.laminatus	cf.auritus		subbellistriatus albertensis	lens laminatus
Lower Jurassic	aalensis				sp.* subflabelliformis* oishii* inexpectatus	sp.		

Camptonectes flourished explosively in the Jurassic period. But the presence of typical *Camptonectes*-striations in certain Permian, Triassic and lower Liassic species indicates that the origin of this genus can be traced back into earlier period than formerly supposed by some authors. It is probable that *Camptonectes* was derived from the Aviculopectinidae parallel to other pectinid groups. In the Lower and Middle Jurassic typical species auch as *Camptonectes auritus* and *C. laminatus* are known in Japan, New Zealand and South America besides various areas of the world. In North America *C. bellistriatus* and its allies occur in the Upper Jurassic. *Radulonectites*, which is character-

ized by *Pleuronectites*-like out-line and ventral radial grooves, is found in the Lias of inner Japan. Several South American species such as *Camptonectes lens* Leanza non Sowerby and *Pecten soneadoensis* Weaver are morphologically similar to the Japanese species. *Eopecten*, a well defined pectinid group, was probably derived from the Aviculopectinidae in Triassic, and Liassic species are more or less common in Europe and India. It is found also in the Upper Jurassic of India and Japan, but seems comparatively rare in Pacific.

Table 22.

ENTOLIUM   * Variamussium

	Europe	India	Indonesia	3N-arc	Japan	E. Siberia	N. America	S. America
Upper Jurassic		partitum			habunokawense* kimurai japonicum yatsujiense inequivalve	nummulare	leachi vulcanicum herleini	
Middle Jurassic	corneolum demissum disciforme		demissum		cf.disciforme		parviaure semlini	pumilis disciforme
Lower Jurassic	hehli lunare calvum cingulatum		donaiensis*	fossatum	sp.* cf.lunare cf.calvum		equable meeki	disciforme hehli coloradoense

(19) Amusiidae especially *Entolium* and *Variamussium* occur commonly in many areas of Indo-Pacific. *Entolium* was probably originated in Upper Palaeozoic *Pernopecten* and flourished in Mesozoic especially Jurassic. Several Liassic species such as *E. calvum* often have shallow byssal notches. But the fact does not mean that they were derived from *Chlamys*-like pectinids, because such a notch can be observed also in *Pernopecten* and some Upper Jurassic *Entolium*. *E. disciforme* is probably a cosmopolitan element, and comparable forms to *E. disciforme* and *E. demissum* occur in the Upper Lias and Bajocian of Japan, Moluccas and South America. *E. japonicum* and *E. kimurai* from the Upper Jurassic of Japan may be descendants from the group of *E. calvum*, and *E. yatsujiense* from the group of *E. lunare*. In North America *Entolium* is also common at some Jurassic horizons. *Entolium nummulare* and its allies which constitute a well defined species group with distinct concentric sculptures, flourished in the period from Oxfordian to Valanginian chiefly in boreal province. *E, inequivalve* from the Upper Jurassic of inner Japan is intimate to *E. nummulare* and also to *E. orbiculare* from the Albio-Cenomanian of Europe and Greenland. *Somapecten* is a characteristic genus of this family. It occurs commonly in the Upper Jurassic of outer Japan, and may be a small branch from *Entolium*. *Variamussium*, which seems ancestral to Cretaceous

Table 23.

PLICATULA * Plicatula (Harpax)

	Europe	India	Indonesia	Japan	E.Siberia	N. America Mexico	S.America
Upper Jurassic	weymouthiana	blanfordi badiensis peregrina	sp.	yatsujiensis dichotomocosta		sportella	vacaensis
Middle Jurassic	fistulosa tuberculosa			weberi cf.spinosa*			
Lower Jurassic	daharensis* spinosa*			subcircularis praenipponica*	spinosa*		rapa

Table 24.

PLAGIOSTOMA

	Europe	India	Indonesia	3N-arc	Japan	E. Siberia	N. America	S. America
Upper Jurassic	laeviusculum rigida callovicum	strigillata blanfordi callovicum			enormicosta cf.cardiiforme			laeviusculum
Middle Jurassic	cardiiforme semicirculare	cf.complanata cardiiforme jumaraense	semicirculare				hazeltonense albertense intermedium	truncatifrons semicirculare
Lower Jurassic	punctatum giganteum compressum nodulosum succinctum garlandica	giganteum		aff.giganteum	matsumotoi kobayashii	aff.ovalis parapunctum subcompressum savrassovi	nodulosum exaltatum	cardiiforme succinctum giganteum nodulosum punctatum

and later *Propeamussium*, occurs at various horizons of Jurassic in Japan, Cochin China, New Zealand, Canada and Neuquén.

(20) Plicatulidae are found already in the Upper Triassic of Japan, but developed extensively in Lias and later stages. Early species such as *P. spinosa*, which probably can be grouped as subgenus *Harpax*, are comparatively large in size, and occur in the Lias of Japan, eastern Siberia and South America and the Middle Jurassic of Moluccas. But they often associate with more typical species of *Plicatula*.

(21) Limidae are represented by many genera in the Jurassic whose assemblage is somewhat different from that of Triassic. *Plagiostoma* is generally considered to have been derived from Triassic *Mysidioptera*. A few species of *Plagiostoma* exist in the Upper Triassic of some regions, but its world-wide development is found after Rhaetic. *Plagiostoma succinctum*, *P. giganteum*, *P. nodulosum*, *P. semicirculare* and *P. cardiiformis* show wide distribution also in the Pacific region. Their stratigraphical occurrence agree roughly with those in Europe. Some authors referred some Jurassic limids to *Acesta*, but *Acesta* was, I think, derived from *Plagiostoma* properly after Jurassic. *Pseudolimea* is common at various horizons in European Jurassic. In Japan the genus occurs already in the Upper Triassic, but Jurassic species are scarcely known in the Pacific region except for *P. duplicata* from the upper Lias of Neuquén. *Antiquilima* is known in the Lias and Aalenian of Europe, and *A. nagatoensis* occurs in the lower Lias of western Japan. The genus resembles at a glance Upper Jurassic and later *Ctenoides*, though their phylogenetic relationship cannot be warranted. *Limatula*, though Jurassic species are sometimes fairly deviated from Recent typical species in outline, is common in many areas of Pacific. *Ctenostreon* is an important member in many Jurassic faunas of Indo-Pacific. *C. proboscideum* are probably a Tethyan elements, and its distribution can be traced in the Middle-Upper Jurassic from Europe to India, Indonesia and Japan. Lower Liassic species are known in western Japan and Amur. In South America several species of *Ctenostreon* with much thickened ligament area such as *C. paucicostatum* appeared in the Lias and succeeded by some Callovian species such as *C. chilense*.

(22) Anomidae are represented by *Placunopsis* in Jurassic period. Some Upper Jurassic species occur in India and New Zealand.

Table 25.

CTENOSTREON

	Europe	India	Indonesia	Japan	E. Siberia	N. America Mexico	S. America
Upper Jurassic	proboscideum			proboscideum		riograndense	neuquense chilense
Middle Jurassic	proboscideum rugosum wrighti pectiniforme	proboscideum	pectiniforme	ojikense sp.		gikshanense	raricostatum pectiniforme wrighti
Lower Jurassic	chlamidiforme terquemi		cf.terquemi	sp. japonicum	orientale		paucicostatum

Table 26.

GRYPHAEA

	Europe	India	N. America	Mexico	S. America
Upper Jurassic	lobata dilatata bilobata	balli moondanensis sicula hennigi bilobata	planoconvexa . calceola var.	mexicana impressimarginata	dilatata leufuensis carinata
Middle Jurassic	sandalina	balli eminens lashioensis cf.vinassai	patera minutula cadominensis		neuquensis cf.santiaguensis tricarinata sandalina subovata calceola
Lower Jurassic	cymbium		cf.cymbium rockymontana		calceola cf.cymbium darwini

Table 27.

LOPHA

	Europe	India	Indonesia	Japan	N. America	S. America
Upper Jurassic	solitaria gregarea marshii	eruca	amor	gregarea cf.eruca cf.marshii sp.	mcevoyi informis	
Middle Jurassic	marshii gregarea solitaria pulligera	marshii gregarea	sp.	spp.		solitaria pulligera
Lower Jurassic				sazanami	? gregarea	longistriata keideli

(23) Ostreidae become more common after Rhaetic, though *Gryphaea*, *Lopha* and *Liostrea* which are the main representative genera of the family appeared already in Triassic times. *Gryphaea* is said to have been derived from *Liostrea* through *Liostrea* (*Catinula*), and the morphic transformation among the three, in fact, seems gradual. *Gryphaea* seems very common in North and South America since Lias besides Europe and India, but the genus is scarcely found

in many areas of western Pacific region. *G. bilobata* and many other Tethyan species cannot be traced into Indonesia, 3N-arc and Japan. It is probably because the geosynclinal sedimentary condition in the western Pacific may have inhibited its development. However, the distribution of sedentary species of *Lopha* extends from Europe and India to Indonesia and Japan. *L. marshii* with broad outline and radiating plications and *Lopha eruca* with narrow outline and divaricate ribs constitute two stocks in the Middle-Upper Jurassic of these regions. *Heterostrea steinmanni* from the Bajocian of Peru is said to possess dimyarian adductors.

(24) Trigoniidae may have evolved polyphyletically from several groups of the Myophoriidae, as suggested by some authors. KOBAYASHI, MORI and TAMURA (1954–1959) studied this family and determined the generic positions of many Jurassic species not only in Japan but also in various areas of Pacific. It was clarified by them that the evolution of trigoniids in the Pacific region is somewhat different from European and Indian regions. The result of their studies can be summerized as follows. *Trigonia* (s. s.) shows worldwide distribution and occurs at various horizons of Jurassic in Indo-Pacific. *Frenguelliella* is common in the Lower and Middle Jurassic of South America, and it is probable that certain species of *Vaugonia* were derived from *Frenguelliella*. It is interesting to see in many species of *Vaugonia* that there are *Frenguelliella, Jaworskiella* and *Vaugonia*-stages in their ontogeny. Some authors suggested that *Vaugonia* was derived from *Myophorella*, but in Japan *Vaugonia* appeared already in lower Lias prior to the first appearance of *Myophorella*—a fact denying the evolutional trend from *Myophorella* to *Vaugonia*. *Vaugonia* flourished in the Middle Jurassic of South America but seems comparatively rare in North America. *Myophorella* is on the contrary more common in north

Table 28.

TRIGONIA

* Frenguelliella
** Jaworskiella

	Europe	India	Indochina	Japan	N. America	Mexico	S.America
Upper Jurassic	reticulata	spitiensis nitida			americana	minuta rudicostata	mirandaensis mollesensis corderoi
Middle Jurassic	elongata cassiope	elongata prora kheraensis tealei	moorei*	sumiyagura			cassiope sterzneri denticulata
Lower Jurassic	costata			senex	cf.denticulata aff. costata litteri		burckhardti** inexpectata* chubutensis tapiai*

Pacific. The distribution of *Myophorella* (*Promyophorella*) *orientalis* extends from north Japan to Mindoro. *Myophorella* (*Haidaia*) is also common in north Pacific and seems especially common in outer Japan and Mexico. *Geratrigonia*, *Prosogyrotrigonia* (Jurassic species), *Latitrigonia*, *Ibotrigonia* and *Nipponitrigonia* are quite interesting groups for the consideration of trigoniid evolution, but their distribution is now confined to Japan and its surroundings. In the Indian region *Indotrigonia* and *Pterotrigonia* are well represented in the Upper Jurassic,

Table 29.

VAUGONIA   * Hijitrigonia

	Europe	Indonesia	3N-arc	Japan	N.America	S. America
Upper Jurassic				yambarensis	obliqua	pichimon colensis
Middle Jurassic	flecta moretoni angulata	mindoroensis	kawhiana	awazuensis yokoyamai geniculata*	obliqua doroschini	ovallei rectangularis praelonga covuncoensis exotica chunumayensis gottschei literata* lycetti*
Lower Jurassic	v-costata* costatula			kodaijimensis kojiwa* yokoyamai niranohamensis namigashira	aff.costatula	

Table 30.

MYOPHORELLA   * Haidaia

	Europe	Indonesia	3N-arc	Japan	N. America Mexico	S. America
Upper Jurassic	perlata hudlestoni clavellata	orientalis molengraffi*		obsoleta orientalis purex* gracilenta* dekaiboda imamurai crenulata* sugayensis	vyschelzkii proscabra* dawsoni* montanaensis ferrieri	
Middle Jurassic	imbricata scarburgensis witchelli signata			sigmoidalis	trafalgarensis devexa undulata	signata
Lower Jurassic	formosa				aff.formosa	

and Jurassic trigoniids faunas are composed of much different genera from Pacific ones. It is concluded that the rise and fall of trigoniids are fairly different among regions, and that some groups show local development in certain limited biogeographical provinces.

(25) Pachicardiidae including *Pachicardia, Heminajas, Trigonodus* and *Cardinioides* developed in the Triassic of various regions, but most genera disappeared before the beginning of Jurassic. Only two endemic species of *Cardinioides* occur in the Lias of inner Japan.

Table 31.

CARDINIA

	Europe	Indonesia	Japan	E. Siberia	N. America	S. America
Middle Jurassic					inexpectata	jurensis
Lower Jurassic	philea hybrida regularis henocquii concinna	aff. philea nachamensis latitruncata	orientalis toriyamai	nostra aff. collenoti amurensis aff. hennocquii	regularis	densestriata andium

(26) Cardiniidae are known already from the Carnic of Japan, but the extensive development of *Cardinia* is known in Rhaetic and lower-middle Lias. In the Pacific region Liassic species are found in Japan, eastern Siberia, Indochina, Canada and South America, but the constituent species are quite different from European faunas. Splendidly imbricated species, which I (1958) treated as a subgroup of *C. hybrida* are distributed in northern Pacific, while the subgroup of *C. densestriata*, characterized by the numerous concentric lines between the imbrications is restricted to South America. Typical *Cardinia* with large dimensions and more or less elongate-ovate outline occurs in Indochina and Japan besides Europe but seems comparatively rare in Pacific. In the Indian region *Cardinia* probably has not been found, but it is possibly due to the scarceness of lower Liassic deposits. Some species of Triassic *Palaeopharus* and *Pleurophorus* show similar internal characters to *Cardinia*, and it is highly probable that *Cardinia* was derived from certain preheterodont pelecypods.

(27) Myoconchidae are persistent from Triassic. Jurassic species in the Pacific region can be grouped into *Myoconcha* from South America and *Kalentera* from New Zealand. *Myoconcha* is known in the Lias of eastern Siberia and (?) Upper Jurassic of Japan, but this family seems rare in other areas of Pacific.

(28) Astartidae appeared at first in Upper Triassic and developed extensively in Jurassic. Cretaceous species are also very common in various areas

Table 32.

ASTARTE * Coelastarte

	Europe	India	Indonesia	3N-arc	Japan	N. America	Mexico	S. America
Upper Jurassic	ovata subdepressa	spitiensis hermanni sowerbyana scytalis	eastoni borneensis		cf.spitiensis kambarensis sakamotoensis ogawensis higoensis defecta subdepressa somensis* harrisonensis morion	meeki packardi	malonensis cf.rathieri microphyes breviacola grubbi magnoliana smackoverensis hazzardi	"minima"
Middle Jurassic	wiltoni pumila excavata* depressa elegans	rustica	elegans	spitiensis	cf.cardiniiformis*	sonniniarum		pulmae mirabilis gracilis excavata* andium
Lower Jurassic	subtetragona lurida voltzi		subcarinata voltzi		cardiniiformis* spp.		cf.antipodum	subtetragona antipodum aureliae fontis

but Recent ones are not numerous, their distribution being confined properly to cold seas. Liassic species are generally small in size, and typical species with large dimensions, prosogyrous umbo, ventral crenules and characteristic shell- convexity flourished chiefly in Aalenian and later. Typical *Astrate* is common in the Middle Jurassic of Cutch and South America and Upper Jurassic of Cutch, Himalayas, Japan and Mexico. *A. spitiensis* occur typically in the Uppermost Jurassic of Himalayas, and allied forms are found also in New Zealand and Japan. *Coelastarte* is known in Bajocian and later in Europe and South America, but in Japan *C. cardiniiformis* appeared already in Hettangian, though it has not distinct ventral crenulations. *Praeconia* appeared in the lower Lias of Japan just as in Europe.

(29) Neomiodontidae including several Mesozoic cyrenoid genera at first appeared already in Lias prior to the Corbiculidae. *Eomiodon* existed in the lower Lias of Japan and flourished until Bajocian, but in Tethys regions its development is found in Bathonian and later. *Crenotrapezium*, which was probably derived from *Eotrapezium*-like cyprinid pelecypods and is characterized by the carinated trigonal outline and elongated lateral teeth with numerous transverse crenulations, often associates with *Eomiodon* in the Lias of Japan. However, the two genera are scarcely known in other areas of the Pacific region.

(30) Corbiculidae at least in part may have derived from the Arcticidae and Neomiodontidae in late Jurassic and early Cretaceous times, and may be a polyphyletic family. Although some Jurassic cyrenoids were referred to *Corbicula* (=*Cyrena*), *Polymesoda* and *Batissa* in Japan and some other areas, none is typical of those genera. Only *Filosina*, which is typically known in the Wealden of Europe and said to have arisen from Upper Jurassic *Eocallista*,

Table 33.

EOMIODON

	Europe	India	Indonesia	Japan
Upper Jurassic	cuneatus			kumamotoensis
Middle Jurassic	fimbriatus angulatus nortonensis	indicus namtuensis namyauensis	chumphonensis	vulgaris
Lower Jurassic				vulgaris lunulatus

occurs in the Purbeckian or Wealden beds of north Japan. The elongation and crenulation of lateral teeth, which are commonly seen in many genera of the Corbiculidae and Neomiodontidae, are a marked tendency in brackish and non-marine heterodont pelecypods.

(31) Arcticidae (=Cyprinidae) flourished in Jurassic and Cretaceous times, and constitute an ancestral group to Cretaceous and later venerid pelecypods. Although many characteristic genera are known in the European Jurassic, Jurassic species seem less common in the Pacific region. Several species from the Bajocian of Canada and Upper Jurassic of Mexico and Western Interior were referred to *Arctica*. In Japan *Arctica* (*Somarctica*) which is characterized by the smaller anterior cardinal 3a and apparently intermediate between *Eocallista* and *Arctica* (s. s.), occurs in the Upper Jurassic. *Yokoyamaina*, having a distinct pallial sinus and cyprinid like dentition, is found abundantly in the lower-middle Lias of Japan, though the family reference is uncertain. Besides, *Isocyprina*, *Eocallista* and *Anisocardia* occur sporadically in the Middle and Upper Jurassic of Japan.

(32) Lucinidae are said to have developed since Triassic. *Lucina* (s. l.) *hasei* from the lower Lias of western Japan has subvertically elongated ad- ductor scars of *Lucina*-type, A lot of Jurassic species were hitherto described as *Lucina* from South America, Mexico and Japan besides Europe, but their generic references should be revised in future, because typical Recent species of *Lucina* has almost edentulous hingement and may be fairly deviated from normal Jurassic species.

(33) Fimbriidae (=Corbidae) including *Fimbria*, *Sphaeriola* and *Sphaera*

flourished especially in Jurassic. *Sphaera* is known chiefly in the Middle
Jurassic of Europe, but in Japan, eastern Siberia and New Zealand the genus
occurs already in the lower Lias. It seems highly probable that *Sphaeriola*
evolved from Triassic *Schafhäutlia* by the differentiation of chevron-like cardinal
tooth 3 into distinct 3a and 3b. Jurassic *Fimbria* occurs commonly in Europe
and north Africa, but in the Pacific only two forms are known in the lower
Lias of Japan and Middle Jurassic of South America.

Table 34.

TANCREDIA

	Europe	Indonesia	3N-arc	Japan	N. America Mexico	S. America
Upper Jurassic	curtansata		plana	rostrata sp.	louisianensis texana knowltoni	cf.donaciformis
Middle Jurassic	truncata angulata extensa		allani		canadensis	
Lower Jurassic		marcignyana				

Table 35.

PROTOCARDIA

	Europe	India	Indonesia	Japan	N. America	S. America
Upper Jurassic			tenuicostata multiformis crassicosta	morii tosensis sp.	shumardi schucherti	
Middle Jurassic	buckmani stricklandi striatula	grandidieri		inaii	obliquata erecta	substricklandi striatula
Lower Jurassic	philippianum rhaetica		philippianum	kurumensis onoi		koeki cf.hillana

(34)   Tancrediidae and Quenstedtiidae flourished world-widely in the Middle and Upper Jurassic. *Tancredia* and *Quenstedtia* occur commonly in the Upper Jurassic of Mexico and Western Interior, but seem rather rare in the western Pacific region.

(35)   Cardiidae appeared in Triassic and flourished in Jurassic and later. The greater part of Jurassic species of the family belongs to *Protocardia* which survived until Cretaceous and is succeeded by *Nemocardium* in Cenozoic. *Protocardia* seems an euripic genus and occurs abundantly in various facies in the Jurassic of Japan, Burma, Borneo, North and South Americas. *Cardium asaphum* and *C.* (s. l.) *naganoense* respectively from the Lias of Neuquén and Japan show much different surface-ornamentation from *Protocardia*. The two species are, of course, not typical *Cardium*, but imply the presence of other stocks of the Cardiidae than *Protocardia*.

Table 36.

CORBULA

	Europe	India	Indonesia	Japan	N. America
Upper Jurassic	oxoniensis		borneensis eastonii vogeli	sp. globosa	maloniana
Middle Jurassic	buckmani lyrata	lyrata cf.involuta			munda
Lower Jurassic					

(36)   Corbulidae appeared probably at first in Middle Jurassic. Bathonian and Callovian species of *Corbula*, though their generic reference should be further examined, are common in India, (?) Borneo and Western Interior of North America.

(37)   Pholadidae mostly composed of boring shells occur at first in (?) Middle Jurassic with the appearance of *Myopholas*. A comparable species with Tethyan *M. acuticostata* occurs in the Upper Jurassic of Japan.

(38)   Pleuromyacidae are common in every stage from Triassic to Lower Cretaceous, and numerous species of *Pleuromya* developed in Indo-Pacific as well as in Europe. In North America Bajocian and Callovian species are especially common, while only a few species are known in each area of western

Table 37.

PLEUROMYA

	Europe	India	Indonesia	3N-arc	Japan	E. Siberia	N. America Mexico	S. America
Upper Jurassic	alduini uniformis	uniformis	alduini		punctostriae hidensis	impressa	inconstans subcompressa summissiornata obtusiprorata postculminata	cf.varians cf.alduini
Middle Jurassic	uniformis marginata alduini jurassi			milleformis			weberensis rhynchophora oblonga nuda hectica burnsi antolycus chlutosensis simplex	jurassi gottschei
Lower Jurassic	rotundata unioides striatula liasina			urnula	hashidatensis sp.		cf.gregarius yukonensis	striatula rotundata liasina cf.unioides

Table 38.

PHOLADOMYA   * Tetorimya

	Europe	India	Indonesia	Japan	N. America Mexico	S. America
Upper Jurassic	donacinna hemicardia protei multicostata uralensis*	somensis	cf.multicostata	somensis carinata*	marcoui paucicostata praeposita inequiplicata kingi tosta panderi*	plagemanni
Middle Jurassic			cf.angustata	sp.		acostae abbreviata fidicula
Lower Jurassic	fidicula voltzi ambigua				donacina	andina corrugata cf.fortunata ambigua hemicardia voltzi

Pacific. South American species from the Lias and Bajocian are mostly identical or closely allied to European famous species.

(39) Pholadomyacidae also appeared in Triassic but their explosive development is found in Jurassic. *Pholadomya* is quite common in the upper Lias and Bajocian of South America and Upper Jurassic of North America and Mexico. In the western Pacific region, however, the genus seems uncommon, and it is probably due to the predominance of coarse clastic and geosynclinal sediments and impredominance of marly facies of calm sedimentary con-

Table 39.

GONIOMYA

	Europe	3N-arc	Japan	N. America	S. America
Upper Jurassic	literata	depressa	nonvscripta		
Middle Jurassic	hemicostata literata v-scripta duboisi proboscidea			sp.	cf.duboisi
Lower Jurassic	heteropleura			aff.heteropleura	proboscidea sp.

Table 40.

HOMOMYA

	Europe	India	3N-arc	Japan	N. America	S. America
Upper Jurassic	gibbosa			gibbosa	gallatinensis	gracilis
Middle Jurassic	gibbosa		signicollina		jurozephyriensis	gibbosa
Lower Jurassic				satoi		neuquena bodenbenderi obliquata

dition where *Pholadomya* and other thin-shelled myacids developed. It may be the same as to the distribution of Jurassic *Gryphaea*. *Tetorimya carinata*, an aberrant myacid, occurs in the (?) Oxfordian of inner Japan. Similar species are known in the Oxfordian of Ural and Upper Jurassic of Alaska, and the genus flourished chiefly in boreal province. *Homomya* occurs in the Upper Lias, Bajocian, and Upper Jurassic of Japan, New Zealand, North America and South America. *H. gibbosa* seems a cosmopolitan species. *Goniomya* is com-

paratively rare except for several species from the Lias of Canada and Neu-
quén and Upper Jurassic of Himalayas, Queensland and Japan. *Neoburmesia* is
a characteristic genus found in the Upper Jurassic of Japan. The absence of
chondrophore suggests that the genus belongs to the Pholadomyacidae instead
of the Burmesiidae.

(40) Burmesiidae, though the taxonomic position has not been firmly set-
tled, seem a characteristic family found chiefly in the Noric-Rhaetic of south-
eastern Asia. A lower Liassic species of *Burmesia* is found in north Japan,
and the range of the family extends into Jurassic.

Table 41.

THRACIA

	Europe	Japan	E. Siberia	N. America
Upper Jurassic·	lata depressa	fukushimensis shokawensis	cf.lata	maloniana montanaensis weedi .canadensis
Middle Jurassic	depressa lens elongata			dubia convexa
Lower Jurassic		sp. subrhombica		

(41) Thraciidae appeared at first in Triassic, and flourished in Jurassic.
Thracia is common in the shaly facies of Japan, Siberia and North America
besides Europe, but the genus is scarcely known in southern Pacific.

(42) Cuspidariidae flourished probably after Jurassic, but several species
from the Upper Triassic and Jurassic of southeastern Asia and Japan constitute
a well defined taxonomic group showing *Cuspidaria*-like rostrate outline, and
may belong to the family.

Summary

For the last ten years the greater part of the Jurassic pelecypod faunas
in many localized sedimentary areas of Japan was described by KOBAYASHI,
MORI, TAMURA, KIMURA and myself. More than 90 genera and more than 350
forms have been distinguished in various Jurassic formations of Kitakami,
Hida, Nagato, Soma and the Outer Zone of Southwest Japan. Pelecypods are
the most ubiquitous fossil group in these regions, and the faunas seem im-

portant for the stratigraphical, palaeoecological and palaeobiographical consi-
derations besides the palaeontology proper.   In this paper I summerize and
discuss their stratigraphical and geographical distribution, zonation, palaeo-
ecology and palaeobiogeography, based on the hitherto published taxonomic
descriptions and my field observations, and make some interpretations on the
pelecypod evolution in the Pacific region.

In the Kitakami region 17 faunules, which are characterized respectively by
Burmesia japonica, Geretrigonia hosourensis, Trigonia senex, Mcleagrinella sp.,
Variamussium sp., *Inoceramus kudoi, Vaugonia kodaijimensis, Trigonia sumi-
yagura, Kobayashites hemicylindricus, Chlamys kobayashii, Inoceramus karakuwen-
sis, Inoceramus hashiurensis, Myophorella orientalis, Parallelodon kesennumensis,
Myophorella obsoleta* and *Filosina jusanhamensis*, are important for biostrati-
graphy and intraprovincial correlation.   The Kuruma-Tetori fauna of the Hida
region comprises 18 faunules characterized by *Radulonectites japonicus, Chlamys
kurumensis, Bakevellia ohishiensis, Bakevellia negoyensis, Pleuromya hashidaten-
sis, "Camptonectes"* sp., *Bakevellia magnissima, Meleagrinella* sp., *Geratrigonia
kurumensis, Inoceramus hamadae, Inoceramus* cf. *nitescens, Latitrigonia tetori-
ensis, Nipponitrigonia sagawai, Inoceramus maedae, Tetorimya carinata, Entolium
inequivalve, Vaugonia yambarensis* and *"Corbicula" tetoriensis*, though their ages
are not always determinable strictly.   In the Toyora region 8 faunules repre-
sented by *Cardinia toriyamai, Prosogyrotrigonia inouyei, Oxytoma kobayashii,
Parainoceramus lunaris, Parainoceramus matsumotoi, Posidonia* sp. ex gr. *ornati,
Inoceramus* sp. ex gr. *fuscus* and *Inoceramus utanoensis* occur in ascending
order.

Because of the considerable dependence of pelecypod distribution on facies,
the faunas are important facies-indicators in the Japanese Jurassic.   In the
Kitakami region and the Inner Zone of Southwest Japan, the fossiliferous
sediments can be roughly divided into three categories, namely ammonite-facies
(off-shore neritic shales), trigoniid-facies (near-shore or littoral sandstones) and
cyrenoid-facies (embayment shales and sandstones).   Trigoniid-facies shows
generally somewhat agitated sedimentary condition, and ammonite- and cyre-
noid-facies calm and somewhat stagnant environments.   *Inoceramus, Posidonia,
Pleuromya* and some other thin-shelled forms are predominant in the ammonite-
facies, *Oxytoma*, normal trigoniids, prionodonts and heterodonts with heavy tests
in the trigoniid-facies, and *Bakevellia Isognomon, Mytilus, Eomiodon* and some
other cyrenoids fairly characteristic in the cyrenoid-facies.   This division is,
however, inapplicable to the bio-facies of the Outer Zone where calcareous
and open-sea sediments are predominant.

The marked difference of generic and specific assemblage of pelecypods
among Jurassic sedimentary regions of Japan may be partly due to various
sedimentary environments but at the same time must be dependent also on
certain biogeographical isolation.   In the Lower Jurassic, Kitakami, Kuruma
(inclusive of Iwamuro and Yamaoku) and Toyora regions constituted three
distinct faunal provinces.   In the Upper Jurassic the Tetori fauna suggests
an almost distinct province from that of the Outer Zone, but it is found that

the Kitakami, Soma and Torinosu faunas are intimately connected with one
another, as shown with SIMPSON's indices of faunal resemblance. The greater
part of the Kuruma, Tetori and Kitakami pelecypods is endemic, but Tethyan,
Pacific and even cosmopolitan elements are not rare in the sandy or limy facies
of the Toyora, Kitakami (in part), Soma and Torinosu faunal provinces. In
certain stages of Middle-Upper Jurassic boreal elements are found in the
Tetori and Toyora regions. The differentiation of Jurassic fauna into the
outer and inner suits is attributable to the development of " Eo-nippon Cordil-
lera ", a land barrier, which stretched longitudinally from west Japan to north-
east Japan.

The evolution of Mesozoic pelecypods seems fairly different in many re-
spects between the Pacific and European regions. There are, of course, many
common genera and subgenera between the two regions, but some appeared
much earlier in one region than the other. For instance, *Oxytoma*, *Vaugonia*,
Cardinia, *Coelastarte*, *Sphaeriola* and some other genera appeared somewhat
earlier in eastern Asia. South American and Indian faunas bear marked af-
finities with European ones, but many characteristic genera and species are
found in the Pacific region especially in Japan, Indonesia and 3N-arc.

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I. HAYAMI

Jurassic Fossils from Nagato and Kitakami

Plate XIV

Explanation of Plate XIV

Figs. 1a-b. *"Hildoceras" chrysanthemum* YOKOYAMA. Compressed specimen with nearly complete body chamber and operculum near the aperture, ×1.5. Loc. Aptychi-shale of the Nishinakayama formation (Ng beds) at Ishimachi, Toyoda town, Yamaguchi Prefecture (Toarcian).

Figs. 2–3. *"Cornaptychus"* a sp., ×2. Opercula of a harpoceratid like the preceding species. Loc. ditto.

Fig. 4. *"Cornaptychus"* b sp., ×2. Loc. Aptychi-shale of the Nishinakayama formation (Ne beds) at the southwest of Ishimachi (upper Pliensbachian).

Fig. 5. *Pentacrinus* sp., ×3. Loc. *Cardinia*-sandstone of the Higashinagano formation at the south of Higashinagano, Toyoda town. (lower Lias).

Fig. 6. *Posidonia* sp. ex gr. *ornati* QUENSTEDT. Slab with many specimens, ×2. Loc. *Posidonia*-shale of the Utano formation (Up beds) at Todani, southwest of Ishimachi (Aalenian).

Fig. 7. *Amonotis* n. sp. Slab with many specimens, ×3. Loc. *Amonotis*-shale of the Nishinakayama formation (Ne beds) at the south west of Ishimachi (upper Pliensbachian).

Fig. 8. *Myophorella* (*Haidaia*) *crenulata* KOBAYASHI and TAMURA. Rubber cast from left external mould, ×1. Loc. *Trigonia*-sandstone of the Mone formation (Sm_2 member) at Udohama of Oshima, Kesennuma city, Miyagi Prefecture (Oxfordian or Kimmeridgian).

Fig. 9. ? Trail of a gastropod. ×1. Loc. Ah_1 member of the Arato formation at the west of Hosoura, Shizukawa town, Miyagi Prefecture.

All specimens illustrated are kept in the Geological Institute, University of Tokyo. Photo by UEKI.
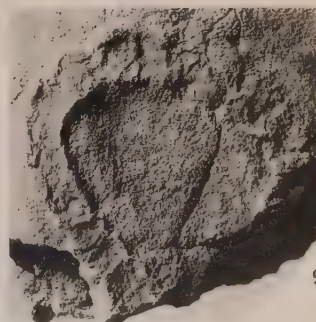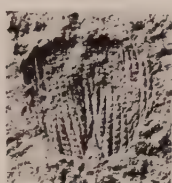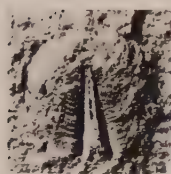
STUDIES ON THE OSTRACODA FROM JAPAN: HINGEMENT

By

Tetsuro HANAI

1. Introduction

The body wall of the Ostracoda turns outward in the centro-dorsal area and forms the inner surface of the epidermis by extending toward the anterior, ventral and posterior areas. A calcified outer lamella is formed on the outer surface of the epidermis, and simultaneously the marginal area of the inner lamella, the chitin lining of the epidermis, is calcified to form the duplicature. On the surface of the calcified marginal duplicature, parallel crests develop along the free margin. They fuse along the dorsal hinge margin, however, and progressively evolve from simple into complicated hingement through differentiation. Therefore, the hingement and the marginal crests on the duplicature are homologous. Other paleontologically important taxonomic characters such as outline, ornamentation and impressions on either surface of the outer lamella (e.g. sulcus, muscle scars, ventral structures), pore canals to accommodate the filament connecting the sensitive setae to scolopoide body, etc., influenced in varying degree by different factors and differ in biological significance from hingement. Thus the ostracod hingement can in no way be compared to pelecypod hingement. In cytheracean species, adult individuals do not show a wide range of variation in their hinge structure (TRIEBEL, 1954). Many authors have emphasized the importance of hingement in taxonomy, especially in generic determination. This is due to the narrow range of hinge variation within a genus. Recent study shows that paleontological conclusions based on detailed study of carapaces, including hinge morphology, do not contradict biological conclusions based on detailed study of the appendages.

Hingement is undoubtedly one of the important taxonomic criteria. However, the writer intends to describe the nature of hinge variation and to investigate limitations of hingement as a taxonomic criterion rather than merely to emphasize the importance of hingement in ostracod taxonomy.

2. Acknowledgments

3. Classification of post-Paleozoic ostracode hingement; historical review

ZALÁNYI (1929) was probably the first to propose a morphological classification of the variously developed post-Paleozoic ostracoda hingements. He divided a hinge margin into three hinge elements—anterior, interangular or apical and posterior, and he described the hingement of various podocopan genera in detail. He then grouped all hingements into two types, dentate and non-dentate. The following terminology of lamellibranch dentition was applied to Ostracoda: dysodont, kriptodont, desmodont, taxodont, heterodont, and schizodont. He concluded that the hingement must be considered the most important taxonomic criterion in fossil forms, not only for the species but also for larger systematic units.

In his study of the systematics of fossil Ostracoda, SCHWEYER (1940) classified ostracod hingement into two groups, *Gleichteilige* and *Verschiedenteilige* hingements. He also recognized laio- and dexio-tropismus of the hingement. Further, *Verschiedenteilige* hingement was subdivided into three types— hinge of three elements, hinge of four elements and hinge of more than four elements (five to seven). He concluded that the hingement is the most important generic character, and added without reservation that "Wieviel verschiedene Schlosser, soviel verschiedene Gattungen".

In 1946, BOLD classified podocopan hingement into three types, adont, taxodont and heterodont. Although not always with quite the same meaning, this was followed by KINGMA (1948) and GREKOFF (1952, 1953). KINGMA also applied a term *Archicythereis* hingement for immature forms of both heterodont and taxodont hingement. The classification of podocopan hingement originated by ZALÁNYI was further advanced by MALKIN (1953); she used the following seven terms for dentition: adont or dysodont, desmodont, taxodont, crasidont, heterodont, cryptodont and archidont. Of these crasidont and archidont were new terms. The former was introduced for hingement which combines features of taxodont and heterodont dentition and the latter for the *Archicythereis* hingement of KINGMA.

In his important study of homeomorphic genera of cytheracean Ostracoda,

TRIEBEL (1950) introduced term merodont for hingement in which only one valve carries hinge teeth, and term amphidont for hingement in which both valves are provided with one or more hinge teeth. He restricted the meaning of taxodont to simple (isomorphic) type hingement and proposed term entomodont for taxodont dentition of complicated (heteromorphic) type. He also used the term schizodont of ZALÁNYI in a restricted sense. These terms are used by TRIEBEL and his followers in a binary manner to restrict their meaning, e. g. merodont-entomodont. TRIEBEL concludes that the merodont hinge probably precedes the amphidont hinge phyllogenetically.

In 1952, BEROUŠEK classified ostracod hingement into two groups, simple and composite hingement. He concluded that the fundamental structure of the hinge line is constant for each genus and that the hingement is therefore the most important single taxonomic character. He used hinge formulae such as $\frac{t\ s\ g\ t}{s\ t\ b\ s}$ and $\frac{t\ g\ t}{s\ b\ s}$ for description, where, t, s, g, and b are abbreviation of teeth, socket, groove and bar, respectively.

In 1955, POKORNÝ discussed phylomorphogenesis of the hingement of Hemicytherinae using the term protogenic hinge teeth for the terminal teeth which appear in the hinge structure as the first teeth, and term protodont valve for a valve with protogenic teeth. He (1957) further advanced FASSBINDER's (1912) and ZALÁNYI's (1929) observations of the hingement from the standpoint of the homology with the structures of the free margin. He recognized two types of hingement, holosolenic and hemisolenic. The former has a continuous contact groove around the entire periphery as in Cytherella, whereas in the latter the contact groove is interrupted by fusion of the selvage and list as in Thlipsurella. He concluded that the podocopa arose from a holosolenic Platycopa ancester. His view on the hingement is well summarized in his text-book on micro-paleontology.

In 1956, SYLVESTER-BRADLEY discussed the structure, evolution and nomenclature of the ostracod hinge. He classified ostracod hingement into the following six types: lophodont, merodont, entomodont, lobodont, schizodont and amphidont. Lophodont and lobodont are newly introduced terms. The definitions of other terms are also considerably modified. He concludes that the study has justified classification of hinge types according to the stage reached in a morphogenetic series. He also concludes that the primitive hinge is tripartite and that more specialized hinge types originate by subdivision of the median element.

The writer (1957) proposed the term pentodont for a new type of hingement in which the median element is subdivided into three segments. He also proposed the term pseudadont for hingement which resembles adont but which actually developes in the last molt stage from the desmodont hingement of the preceding molt.

MALZ (1958) pointed out that because of the wide variability of ostracod hingement, an attempt to name each hinge type could lead to a confusing proliferation of concepts with their corresponding terms. He therefore pro-

posed use of such terms as "*Ogmoconcha*-hinge" and "*Lophocythere*-hinge" which at once bring to mind the correct hinge type without the neccessity of special terminology. The terms introduced by TRIEBEL could be used for discussion of the ontogeny and phylogeny of the hingement.

In 1958, HOWE and LAURENCICH present illustrated definitions of the most common types of Cretaceous hingement: adont, prionodont, lophodont, merodont (paleomerodont, holomerodont, antimerodont, hemimerodont), entomodont, lobodont, amphidont (paramphidont, hemiamphidont, holamphidont), schizodont, gongylodont. In their classification, the new term prionodont corresponds to taxodont of TRIEBEL; merodont and amphidont as originated by TREIBEL and modified by SYLVESTER-BRADLEY are broken down into several varieties; and the new term gongylodont is proposed for *Loxoconcha*-type hingement. They consider merodont hingement to be an outgrowth of either adont or prionodont hingement.

4. Present status of hinge classification

It can be seen from the above historical review that existing classifications of hingement fall into two major groups:

1) The classifications based on the segmentation of the hingement, e. g. Gleichteilige and Verschiedenteilige (SCHWEYER, 1940); Einfacheren and Komplizierteren (TRIEBEL, 1950); Simple* and Composite (BEROUŠEK, 1952); Simple and Compound (SYLVESTER-BRADLEY, 1956); Isomorphen and Heteromorphen (TRIEBEL, 1959).

2) The classification based on the homology of the hingement with the free margins of the valves. e. g. Holosolen and Hemisolen (POKORNY, 1957, 1959).

There is a third type of classification based on the "Schalentropismus". The tropismus, however, has not generally been considered to be of much taxonomic importance.

The major groupings mentioned above are further subdivided mainly on the basis of the segmentation and modification of the hinge elements. The following four groups of terms have so far been employed to describe the podocopan hinge:

1) Terms borrowed from those used to describe the lamellibranch hinge. This was first used by ZALÁNYI (1929) and some terms have also been used by BOLD (1946), KINGMA (1948), GREKOFF (1952, 1953), MALKIN (1953) etc. The following terms belong in this group:

Dysodont: without teeth (ZALÁNYI, 1929)=Adont

Adont: no real teeth occur (BOLD, 1946, KINGMA, 1948, GREKOFF, 1952, 1953, MALKIN, 1953). Some authors (i. e. BOLD, 1946, KINGMA, 1948) include here not only simple hinges but also the tripartite types of *Bythocythere, Paradoxostoma,*

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* KESLING (1951) classified hingement in three types: simple, ridge and groove, and tooth and socket structures. He used the term "simple" to designate a hingement with the edge of one valve fitting against or under the edge of the opposite valve.

"*Cytherideis*" etc. The simple hinge has most recently been defined as one which possesses a single element with no crenulation (HOWE and LAURENCICH, 1958).

Kriptodont: small projections and crest on the hinge margins of one valve and corresponding small groove and sockets on the other, e. g. *Cytheridella* (ZALÁNYI, 1929). According to MALKIN (1953), the term appears to apply only to immature shells. Actually, however, it occurs in adult specimens.

Desmodont: a long crest on one valve with a corresponding channel-shaped depression on the other, e. g. "*Cytherides*" (ZALÁNYI, 1929, MALKIN, 1953). In the above definition, anterior and posterior hinge elements were not described. The writer (1959) redefined the term desmodont as a hinge type which consists of three non-crenulated parts, i. e. a long anterior groove, a median ridge and a rather short or sometimes socket-like posterior groove in the left valve and a complementary long anterior ridge, a median groove and a short or sometimes knob-like posterior ridge in the right valve (HANAI, 1959).

Taxodont: many similar narrow toothlets vertical to the flange, forming a more or less continuous series of toothlets, e. g. *Xestoleberis*, *Cytheridea* (ZALÁNYI, 1929). The original definition is applicable to both simple and tripartite hingement. Specialists in post-Paleozoic Ostracoda have restricted this term to hingement in which the crenulate terminal teeth (sockets) are connected by a crenulate groove (bar) (BOLD, 1946, KINGMA, 1948, GREKOFF, 1952, 1953). Specialists in Paleozoic Ostracoda apply this term to isomorphic hingement (SWARTZ, 1949 etc.). Recently the term taxodont has been restricted to hingement in which the denticles are not grouped into three elements, e. g. *Herrmannina*, *Youngiella* (TRIEBEL, 1950).

Heterodont: true hinge teeth and corresponding sockets occur on the anterior and posterior hinge margins, e. g. *Loxoconcha*, *Cythereis*, *Cythere* (ZALÁNYI, 1929). The classification of *Cythere* was so confused in 1929 that the *Cythere* given by ZALÁNYI as an example of heterodont hingement may not be true *Cythere*. High pointed or slightly crenulate teeth occur in one or both valves, while a median ridge usually occurs in one valve and a groove in the other (BOLD, 1946, KINGMA, 1948, GREKOFF, 1952, 1953). MALKIN (1953) restricted the usage of heterodont to forms with a smooth median element. Examples of heterodont hingement given by various authors are more or less heterogeneous, as they include *Cytheromorpha*, *Cytherura*, *Cytheretta* and *Trachyleberis*.

Schizodont: a kind of heterodont. At the anterior or more often posterior hinge margin, two closely adjacent teeth (perhaps through the fission of a single tooth) correspond to a single socket of opposite hinge margin (ZALÁNYI, 1929). ZALÁNYI did not give any examples of this type of hingement. Modern usage of this term is that of TRIEBEL (1950) which restricts the term to a hinge type which occurs in *Palmenella*, *Paijenborchella* and *Schizocythere* in which the anterior hinge tooth of each valves is split (TRIEBEL, 1950). The term has been used by many authors including SYLVESTER-BRADLEY (1956) and HOWE and LAURENCICH (1958) in the same sense as that proposed by

TRIEBEL.

Since the lamellibranch shell and the ostracod carapace are not at all homologous, terms borrowed from those used to describe lamellibranch hingement are not sufficient to cover all podocopid dentition. The following supplementary terms have been proposed:

Crasidont: hingement combining features of taxodont and heterodont dentition in which the taxodont element is subordinate, e. g. *Leguminocythereis*, *Campylocythere* (MALKIN, 1953).

Archidont: *Archicythereis* hingement of KINGMA (1948). Immature hinge indicating primitive or early dentition (MALKIN, 1953).

2) Binary terminology proposed by TRIEBEL (1950). The terms listed below have been used by European authors in the original sense and in original binary usage like merodont-entomodont or amphidont-schizodont. Recently, however, definition of terms has been restricted by SYLVESTER-BRADLEY (1956) and HOWE and LAURENCICH (1958) in order to make them all of the same rank.

Taxodont: see p. 349.

Merodont: only one valve of carapace carries hinge teeth (TRIEBEL, 1950). This original definition includes widely varying types of the hingement. SYLVESTER-BRADLEY (1956) restricted the term to a hinge type which is called taxodont by some authors specialized in post-Paleozoic Ostracoda. Anterior and posterior elements are crenulate, the median element either smooth or crenulate, but not subdivided, e. g. *Cythere* (SYLVESTER-BRADLEY, 1956). Merodont hingement redefined by SYLVESTER-BRADLEY is further subdivided by HOWE and LAURENCICH (1958). See. p. 351.

Amphidont: both valves provided with one or more hinge teeth (TRIEBEL, 1950). This original definition also includes various types of dentition which had mostly been called heterodont by previous authors. SYLVESTER-BRADLEY redefined the term as a hinge type in which the median element is further differentiated into a single anterior tooth and a posterior bar or ridge, e. g. *Dictyocythere*, *Trachyleberis* (SYLVESTER-BRADLEY, 1956). The term amphidont as redefined by SYLVESTER-BRADLEY is further broken down into three varieties by HOWE and LAURENCICH (1958). See p. 351.

Entomodont: crenulate hinge which is divided by more or less deep incisions into three parts (TRIEBEL, 1950). SYLVESTER-BRADLEY restricted this term to a type of hingement in which the median element becomes subdivided, the anterior part remaining dentate, the posterior smooth or finely crenulate (SYLVERSTER-BRADLEY, 1956, HOWE and LAURENCICH, 1958).

Schizodont: see p. 349.

POKORNÝ followed TRIEBEL's hingement terminology. However, he also used the following descriptive terms which are derived from Greek and terminate in "-dont" like other hingement terms, but are not directly concerned with the classification of the hingement.

Protodont: having protogenic teeth; that is terminal teeth which appear in the hinge structure of Ostracoda as the first teeth. They originate from

differentiation of the selvage (POKORNÝ, 1955).

Deuterodont: having the newly formed tooth (POKOREÝ, 1959).

3) Terms which have the same rank value and whose definitions do not overlap. This terminology was proposed by SYLVESTER-BRADLEY (1956) and further modified and advanced by HOWE and LAURENCICH (1958); BENSON (1959) also used this terminology.

Adont: see p. 348.

Prionodont: this corresponds to taxodont of TRIEBEL (1950) and Paleozoic Ostracoda specialists.

Lophodont: hingement is divided into three elements consisting of smooth terminal ridges separated by a long median smooth groove in the smaller valve, e. g. *Bythocythere* and *Camptocythere* (SYLVESTER-BRADLEY, 1956). Examples given by HOWE and LAURENCICH (1958) are *Eucythere* and *Cushmanidea*. This corresponds to desmodont of HANAI (1959). See p. 349.

Merodont: see p. 350.

Paleomerodont: an outgrowth of adont hingement, the terminals of the hingement become crenulate and projecting while the median bar remain smooth, e. g. *Schuleridea* (HOWE and LAURENCICH, 1958).

Holomerodont: similar to paleomerodont, but the median bar is crenulate. An outgrowth of prionodont, e. g. *Haplocytheridea, Stillina* (LAURENCICH, 1957, HOWE and LAURENCICH, 1958).

Antimerodont: projecting terminal elements are crenulate and are separated by a crenulate furrow, e. g. *Clithrocytheridea* (HOWE and LAURENCICH, 1958).

Hemimerodont: similar to antimerodont but median furrow is smooth rather than crenulate, e. g. *Paleocytheridea* (HOWE and LAURENCICH, 1958).

Entomodont: see p. 350.

Lobodont: anterior and anteromedian elements are lobate bosses (SYLVESTER-BRADLEY, 1956). A hinge intermediate between entomodont and amphidont (HOWE and LAURENCICH, 1958).

Amphidont: see p. 350.

Paramphidont: anterior and posterior elements are crenulate; anteromedian element is smooth tooth, posteromedian element is smooth or finely crenulate bar, e. g. *Cythereis* (HOWE and LAURENCICH, 1958).

Hemiamphidont: similar to paramphidont, but anterior element is smooth or stepped, e. g. *Brachycythere* (HOWE and LAURENCICH, 1958).

Holamphidont: similar to paramphidont, but both terminal elements are smooth or stepped, e. g. *Trachyleberis* (HOWE and LAURENCICH, 1958).

Schizodont: see p. 349.

Gongylodont: anterior element of one valve is a down-turned claw, the posterior element a ball-like knob below the dorsal margin. In the opposite valve, the claw is at the posterior end the ball-like knob at the anterior end, e. g. *Loxoconcha* (HOWE and LAURENCICH, 1958).

Other terms proposed are as follows:

Pseudadont: similar to adont, but sometimes have a faint crenulation

along the posterior one-fourth of the hingement. This type of hingement develops in the last molt stage through modification of desmodont hingement, e. g. *Parakrithella* (HANAI, 1959).

Pentodont: anterior and posterior elements of the right valve are smooth teeth; median element is crenulate groove with sockets at its anterior and posterior terminations. In the opposite valve, teeth at the anterior and posterior terminations of the median bar, e. g. *Munseyella* (HANAI, 1957).

4) Other classification not using the special terms which are derived from Greek and terminate in "-dont". This type of classification was employed by SCHWEYER (1940). See p. 346.

5. Data for taxonomic evaluation of the hingement

a. Ontogenetical evidences

HOWE (1936) described pairs of cythereacean forms having similar shape and muscle scar pattern but are different in size and hinge structure, in which the smaller forms have a hinge of the *Archicythereis* type. Further he predicted that the smaller forms would prove to be young molts of species belonging to a variety of genera. Since then various terms derived from the name *Archicythereis*, such as *Archicythereis* hingement, archicytherid hingement and archidont, have been employed by various authors to signify the larval hingement of cytheracean Ostracoda. The hinge structures of the young molt in comparison with those of the adult have been described by various authors for several cythereacean genera (e. g. *Cythereis* by TRIEBEL, 1940; *Macrodentina* by KLINGLER, 1958; *Haplocytheridea* by STEPHENSON, 1941; *Pterygocytheris* by HILL, 1954, etc.).

In 1945, LEROY using the Tertiary trachyleberid Ostracoda, demonstrated that adult amphidont hingement suddenly developes from merodont *Archicythereis*-type hingement in one of the last few instars. This observation of the sudden change of hinge structure was confirmed by POKORNÝ (1952) in Pliocene *Eucythereis* and was further advanced by MALZ (1956) in Jurassic *Macrodentina*. The latter is one of the oldest Ostracoda with distinct amphidont hingement and therefore is of special interest. MALZ further pointed out the importance of hinge ontogeny for evaluation of the homeomorphic genera. See p. 354.

As to the schizodont Ostracoda, TRIEBEL (1950) described the hinge of a young molt of genus *Schizocythere*, which is characterized by a strong round tooth at the distal ends of the terminal elements, while the proximal crenulations of the terminal elements remain unchanged as a low crenulate crest.

Recently, BŁASZYK (1959) described ontogenetic change of hingement of entomodont *Progonocythere* in which the lophodont hingement of the second instar becomes merodont in the third instar and finally adult (sixth instar) entomodont dentition is attained in the fifth instar.

All the descriptions of hinge ontogeny mentioned above show a tendency to develope complicated amphidont dentition from simple merodont dentition.

HANAI (1959), however, found a dissimilar case in the hingement of the genus *Krithe* and its allied genera, in which the three folded *Cushmanidea*-type desmodont hingement suddenly reverts to a relatively simple *Krithe*-type pseudadont hingement during the last molting.

b. Dendrogrammatic evidence

Another source of phylogenetic evidence is the morphological comparison of related contemporaneous forms.

The morphologic limits of one type of hingement can be inferred from a linear arrangement of the contemporaneous forms. Many authors arrange species according to the degree of morphological similarity. In 1957, HANAI illustrated the gradationally variable dentition of some subfamilies (i. e. Leptocytherinae, Cytheropterinae). In Leptocytherinae, he further pointed out the presence of a qualitative morphological " break ", that is, presence or absence of containant by which this group is distinct from any other subfamilies.

From consideration of ontogeny, together with the linear arrangement of related contemporaneous forms, morphogenetic development of the hinge elements can be inferred. In 1955, POKORNÝ, using the subfamily Hemicytherinae, illustrated morphological series showing development of the anterior protogenic tooth and of the median element from primitive archicytherid type to more specialized *Hemicytheria*-type.

c. Phylogenetic evidence

The origin of podocopid hingement is still speculative. KELLET (1943) stated that the widely differing genera of the Cytheracea suggest a polyphyletic origin. She further stated that *Basslerella* is one of the few known Paleozoic forms which seem to be related to the Cytheracea and stated that its hinge teeth are similar to those of the genus *Cytheridea*. TRIEBEL (1954) pointed out the similarity of merodont hingement to that of *Ponderodictya* from the Middle Devonian. SYLVESTER-BRADLEY (1957) inferred that the first Cytheracea were derived from one or more representatives of Quasillitacea toward the close of Paleozoic time and that the primitive hinge was therefore lophodont. The transformation of holosolenic platycopid hingement to hemisolenic podocopid hingement is theoretically reconstructed by POKORNÝ (1957).

TRIEBEL (1938) already recognized changes of the detailed composition of the hingement of *Dolocytheridea hilseana* in the course of its speciation. Phylogenetic transformation of the hingement from merodont, entomodont to amphidont was first demonstrated by SYLVESTER-BRADLEY (1948) in Jurassic *Oligocythereis*, Cretaceous *Cythereis* and Tertiary to Recent *Trachyleberis*.

TRIEBEL (1950) reported two homeomorphic genera which are similar each other in their form and sculpture but differ in the structure of the hinge. This external similarity is explained by TRIEBEL not as an acquisition through convergence but as a result of an early stage of divergence. A pair of homeomorphic genera would, therefore, be formed when the amphidont form

appeared at the first time, because it co-existed with its ancestral merodont form. He (1954) further advanced his study on homeomorphic forms using Jurassic amphidont Ostracoda such as *Macrodentina* and *Amphicythere*, and finally attained the very important conclusion that amphidont hingement is polyphyletic in the Cytheridae. This was the first suggestion of the presence of parallelism in the hinge evolution of the Cytheracean Ostracoda. MALZ (1958) clearly showed the real details of phylogenetic relations of hingement in three subgenera of genus *Macrodentina*. Merodont dentition of *M.* (*Polydentina*) is preserved in early stage of *M.* (*Macrodentina*). Amphidont dentition of *M.* (*Macrodentina*) evolves further to that of *M.* (*Dictyocythere*) in its phylogenetic development.

The occurrence of parallel evolution from primitive entomodont to higher hinge types is also pointed out by SYLVESTER-BRADLEY (1956) in the relationship of the amphidont subfamily Trachyleberidinae to its ancestral entomodont subfamily of Progonocytherinae. Present knowledge of parallel evolution of podocopid hingement is summarized by POKORNÝ (1957) in relation to ostracod taxonomy.

SCHMIDT's (1954) conclusion that phylogenetic change of hinge structure from merodont to amphidont depends on ecological oscillation, such as change of the salinity of the water, was discredited by TRIEBEL (1954). Since then no attempt has been made to identify the cause of phylogenetic transformations of hingement.

6. Basis for judgement in taxonomic evaluation of the hingement

The hinge structure of fossil Ostracoda has been considered a very important taxonomic criterion. ZALÁNYI (1929), TRIEBEL (1941), STEPHENSON (1946), KINGMA (1948), SCHWEYER (1948), BEROUŠEK (1952) etc. have emphasized the prime importance of hingement to ostracod taxonomy, especially at the generic level. ALEXANDER (1933), LEVINSON (1950), POKORNY (1957), however, have asserted that the study of all of the shell structures is the only way to attain a natural classification. As already mentioned, it is quite logical to consider the existence of iterative formation and parallel evolution in hingement. Any classification utilizing the character subjected to the parallel evolution or iterative formation as an indication of close relationship would produce defective conclusions. Hingement should therefore be used with the greatest care (WAGNER, 1957), because the limitations of hingement as a taxonomic criterion is not clear, further, its taxonomic value is considered to differ in each taxonomic group. Therefore, hingement should be evaluated by taking all other characters (outline, sculpture, muscle scars, zone of concrescence, marginal flange and list, pore canals, etc.) into account in various degrees. POKORNÝ (1952, 1957) has pointed out classifications which ignored parallelism (e. g., SCHWEYER, 1949; BEROUŠEK, 1952). Here, it should be noted that the existence of parallelism is inferred on the basis of such characters as adductor muscle scars which are essentially different from hingement in their

biological significance.

As previously mentioned, linear arrangement of contemporaneous hinge-ments shows that there can be considerable variation of hinge structure within one type of hingement (HANAI, 1957). Thus a definition of hingement by a typical form may not cover all varieties. MALZ (1958) mentioned that naming every hinge type with -dont will result in a large number of new names and consequent confusion, due to the many forms of hingement. However, there are ranges of contemporaneous variation and if each type of dentition is de-fined with consideration of the variation, the number of hinge types may not be so large as to cause confusion. For example, the term gongylodont was proposed for hinges of typical *Loxoconcha*-type by HOWE and LAURENCICH (1958). Recently, however, hinges of *Elofsonia*-type have been reported by WAGNER (1957) and also that intermediate type is known (Text-figs. 12, 5). Therefore, it has become clear that considerable deviation from the type of the category exists in gongylodont hingement. As a result the term gon-gylodont can be redefined as variable hinge type.

Any series of hinges shows discontinuous variation when their dendro-gramatic arrangement is studied in detail. The taxonomic evaluation of these gaps should be considered with other character in mind. If there are no gaps in other characters, it can be inferred that these two series of dentition are of continuous nature and that the gap is of little or no taxonomic singificance. The relationship between hinges of *Loxoconcha*-type and *Elofsonia*-type is of this nature and they can be group in the same taxonomic category without any difficulties. On the other hand, if there are gaps in other characters as well as in hingement, there is a possibility that the gap in hingement may be significant taxonomically.

Actually, in nature, there are cases when other characters do not show clear gaps as in case of hinges and also when the gaps in other characters do not coincide with those in hingement. The following is an example of such a complicated case. The subfamily Cytherurinae s. l. have hinges of *Cytherura* group and *Cytheropteron* group. The difference between these two groups of hinges is not very clear. Upon detail observation of the course of the inner margin in the *Cytherura* group, it can be seen that there are two types of inner margin, one with the inner margin parallel to the margin (e. g. *Cytherura*), same as those of *Cytheropteron* group, and the other with irregular and modified s-shaped inner margin in the posterior region (e. g. *Semicytherura*). Thus, the gap in hingement does not appear to coincide with that of inner margin. However, variations which connect both types can be found in the inner margin of one species of *Howeina*. Therefore it can be concluded that in this group, the course of proximal boundary of calcified marginal area varies more or less gradually depending on the degree of calcification of the inner lamellae. The nature of the inner margin is therefore, not inconsistent with the presence of the gap in hinge characteristic between the *Cytherura* and *Cytheropteron* groups. When this evidence is considered in evaluating the characters of marginal duplicated areas, there is a gap which approximately

coincides with that of hinges between the group with radial pore canals which are curved and tend to be grouped and those with radial pore canals which are simple, rather straight, few and scattered. In conclusion, considerable taxonomic value as indicator of difference can be placed on the gap between the hinges of both groups.

Hingement, of course, can evolve and may vary vertically as well as horizontally. In this respect also hingement must be evaluated with care (WAGNER, 1957; MALZ, 1958). Even hinges of different types can be placed in the same taxon in order to make a unit of vertical classification, if those hinge types belong to a single evolutionary series, as in the series of *Oligocythereis-Cythereis-Trachyleberis*. In this case specialized amphidont and ancestral entomodont hingement are classified together in the subfamily Trachyleberidinae (SYLVESTER-BRADLEY, 1948). In another example, subgenera from merodont to amphidont can be placed in a single genus as in case of *Macrodentina* (MALZ, 1958). Even in contemporaneous Ostracoda those which have dentitions which are closely related in an evolutionary sense are often classified in a single family-group taxon. For example, holosolenic merodont such as *Haplocytheridea* and hemisolenic merodont and entomodont such as *Clithrocytheridea* and *Cyprideis* may all be placed in the subfamily Cytherideinae (POKORNÝ, 1957). Homeomorphic genera in the sense of TRIEBEL (1950) are taxonomically very close to each other. Therefore, for example, schizodont and merodont are sometimes classified in one taxonomic group. It is, however, advisable to avoid classifying Ostracoda whose dentitions have no relationship vertically or horizontally in one taxonomic group. It is, for example, the opinion of the writer that *Cytheromorpha* should be placed in the Loxoconchinae and not in the Cytherinae because of its gongylodont hingement, if a monotypic subfamily Cytheromorphinae can not be established.

Difference in the degree of development between the anterior half and the posterior half of a hinge has been reported by TRIEBEL (1940), SYLVESTER-BRADLEY (1948), LEVINSON (1950), POKORNÝ (1955) and HANAI (1957). Hingements should be evaluated in one unit as a character complex; care is necessary in evaluation of the details because of the difference in rate of evolution of anterior and posterior hinge elements. It is, for instance, noted that the schizodont hingement of *Schizocythere* has a posterior element comparable to that of merodont *Cnestocythere* rather than that of schizodont *Paijenborchella*.

7. Cenozoic cytheracean hinge types

Here the Cenozoic marine podocopid hinges from Japanese material will be described from the taxonomic point of view delineated above. Hingement is an evolving character with a different rate of evolution for each group. Therefore it must be understood multidimensionally as a character with horizontal variation through divergence and vertical variation through evolution within each group.

Lophodont: see definition given by SYLVESTER-BRADLEY (1956) and HOWE and

LAURENCICH (1958) (p. 351). Dentition as originally defined is observed in a fairly wide range of unrelated groups.

Hingement in which the anterior and posterior elements are smooth as in the case of lophodont, but are sometimes variable to crenulate such as those of Neocytherideidinae or Eucytherinae, will be called desmodont and will be excluded from lophodont.

Bythocytherinae type hinge: dentition of this type has anterior and posterior elements consisting of simple, rather short tooth and socket structure which is always smooth. However, the median element may vary from long, straight and smooth to crenulate and finally to a tripartite crenulate median element formed by deepening of the groove at anterior and posterior terminals in one valve, and protrusion of bar at anterior and posterior terminals in the other. In this type, the hinge bar which forms the median element of the left valve and its corresponding groove in the right valve are well developed. (Text-fig. 1)
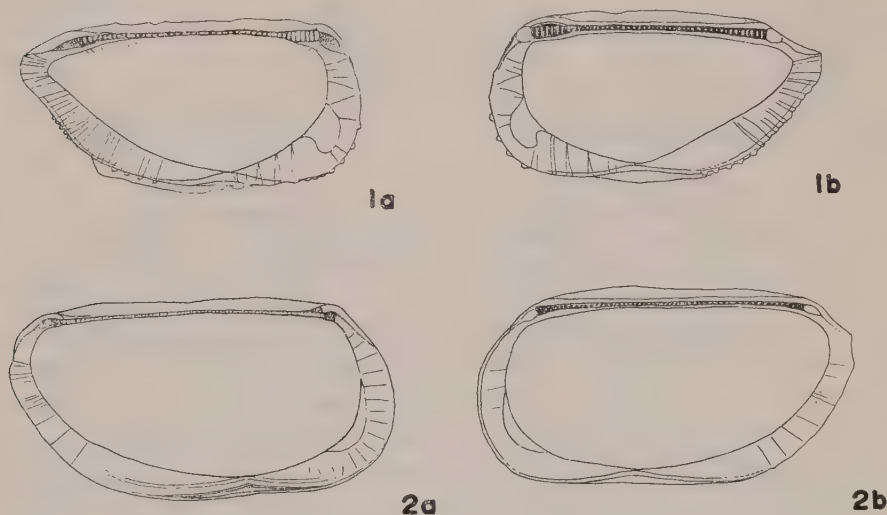
Text-figure 1. Bythocytherinae type lophodont. (×86)
a, left valve. b, right valve.
1. New genus of Bythocytherinae, from Recent beach sand from the shore behind an imperial villa, Hayama-machi, Kanagawa Prefecture.
2. *Bythoceratina* sp., from the same locality as fig. 1.

Cytherurinae type hinge: this type of hinge is characterized in the right valve by terminal knob-like teeth, one at each end of the long blade-like ridge of the selvage of the free margin. In general, these terminal teeth are small and one exists at each terminal, but sometimes the selvage connected to the terminal tooth is incised and can be said to form two or rarely three new teeth. Median element varies from smooth to crenulate. A characteristic which distinguishes this type of hinge structure from other lophodont types is the presence of a strongly developed flange overhanging the actual hinge element of the right valve but not reaching the terminal teeth, so as to make
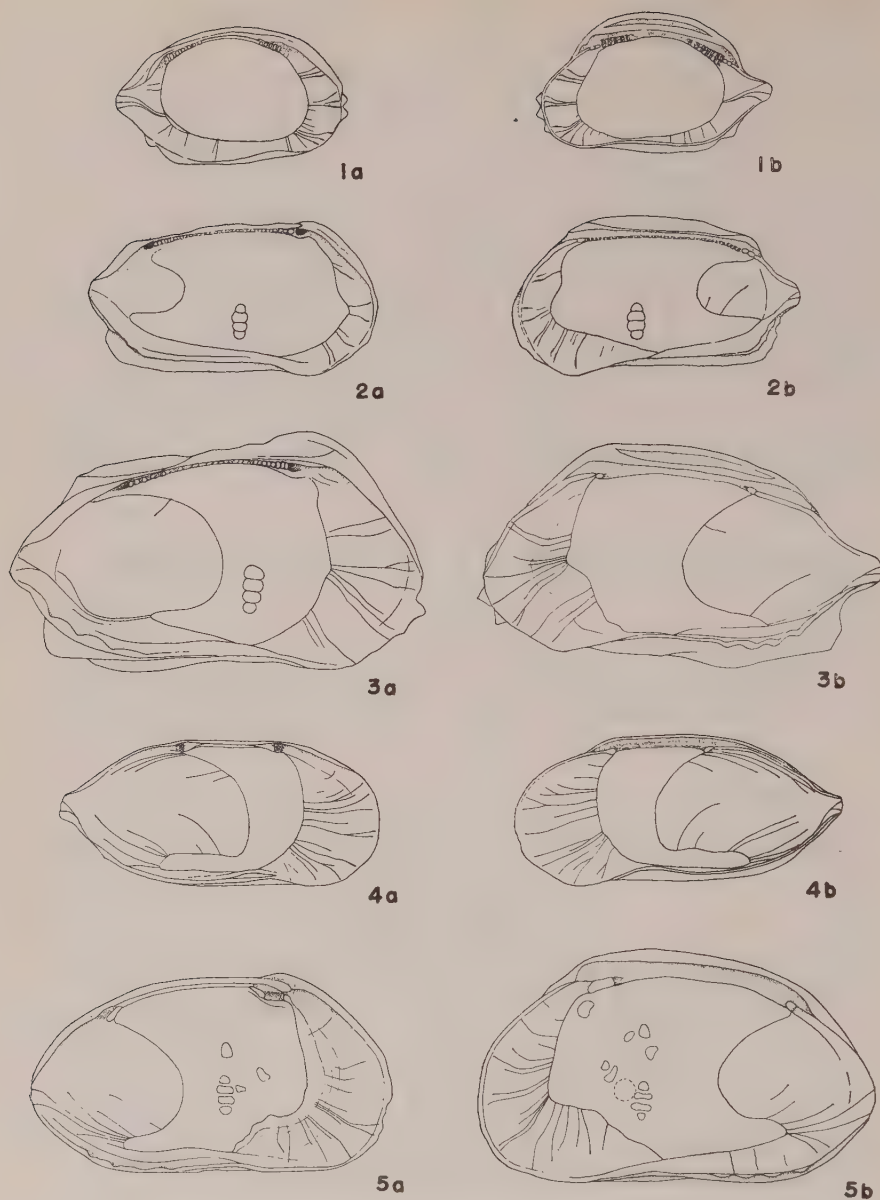
Text-figure 2. Cytherurinae type lophodont. (×72)
a, left valve.   b, right valve.

1. *Hemicytherura cuneata* Hanai, from Recent beach sand from the shore behind an imperial villa, Hayama-machi, Kanagawa Prefecture.

2. *Semicytherura quadrata* (Hanai), from the same locality as fig. 1.

3. *Semicytherura subundata* (Hanai), from Pliocene Sawane formation, the cliff at Mano Bay, Sawane-machi, Sado-gun, Niigata Prefecture.

4. *Cytherura ? miurensis* Hanai, from the same locality as fig. 1.

5. *Howeina camptocytheroidea* Hanai, from Pliocene Setana formation at Kaigarazawa, about 500 mW of Nishinosawa, Kuromatsunai-mura, Suttu-gun, Hokkaido.

a furrow between the overhanging flange and the blade-like ridge of the selv-
age bearing the terminal teeth. This furrow accommodates the selvage of
the left valve, which forms the outer walls of the anterior and posrerior
sockets. (Text-fig. 2)

Paradoxostomatidae type hinge: the dentition of this family is very fragile
but is similar to lophodont of Cytherurinae type. The median element is
long and is similar to the anterior and posterior elements in that it is not
crenulate. In this type of hingement, the median groove of the right valve
is poorly developed or completely obscured. Therefore, the hinge bar which
forms the median element of the left valve merely slips in between the ter-
minal hinge teeth of the right valve. Sometimes the development of anterior
and posterior elements is incomplete and adont hingement is formed. (Text-
fig. 3)

la   lb
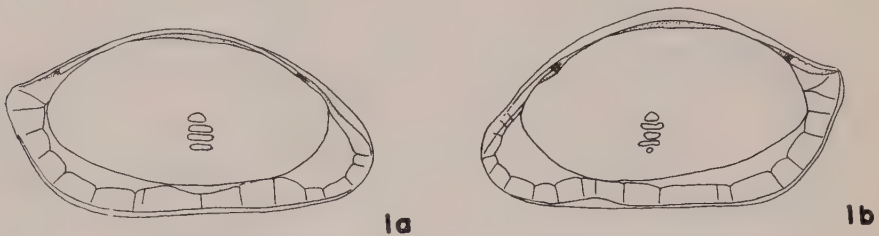
Text-figure 3. Paradoxostomatinae type lophodont. (×91)
a, left valve.   b, right valve.
1. *Paradoxostoma yatsui* KAJIYAMA, from Recent beach sand from the
shore behind an imperial villa, Hayama-machi, Kanagawa Prefecture.

Desmodont: see definition given by HANAI (1959) (p. 349).

Neocytherideidinae type hinge: the necessity of revising HANAI's definition
is here noted. Anterior and posterior hinge elements vary from smooth to
crenulate. In the right valve of this type of hingement the terminal ridges
are projected elements of the selvage, and the median element is formed by
the flange becoming its outer wall by depression of the selvage. On the other
hand, the terminal elements of the left valve are a pair of grooves whose
outer walls are formed by the selvage and the inner walls by the list. The
middle element is a projected ridge formed by fusion of the selvage and list.
This type of hinge has a very long anterior ridge and groove structure and
differs from the Bythocytherinae type lophodont by sometimes having a cre-
nulate posterior element. (Text-fig. 4)

Eucytherinae type hinge: this is closely related to Neocytherideidinae type
hingemet and is considered to be a modified form of desmodont. Variation
to merodont by the development of crenulation on all desmodont hinge
elements is observed in this type of hingement. That is, the variation
ranges from smooth anterior, median and posterior elements through crenu-
late anterior and posterior elements to crenulate anterior, median and pos-
terior elements. However, crenulation does reach the median portion of the
median element. This type hinge varies to adont through separation of the
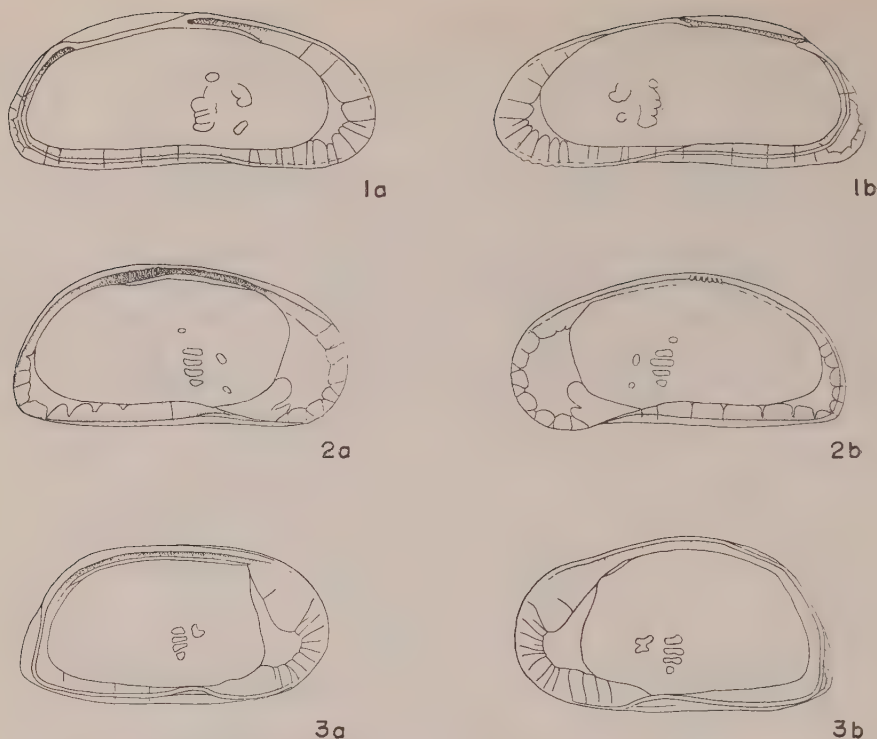
Text-figure 4A. Neocytherideidinae type desmodont and Krithinae type pseudadont. (×68)
a, left valve.   b, right valve.

1. *Cushmanidea miurensis* HANAI, from Recent beach sand from the shore behind an imperial villa, Hayama-machi, Kanagawa Prefecture.

2. *Parakrithella pseudadonta* (HANAI), from the same locality as fig. 1.

3. *Krithe* aff. *bartonensis* (JONES), from the Sawane formation from a cliff at Mano Bay, Sawane-machi, Sado-gun, Niigata Prefecture.
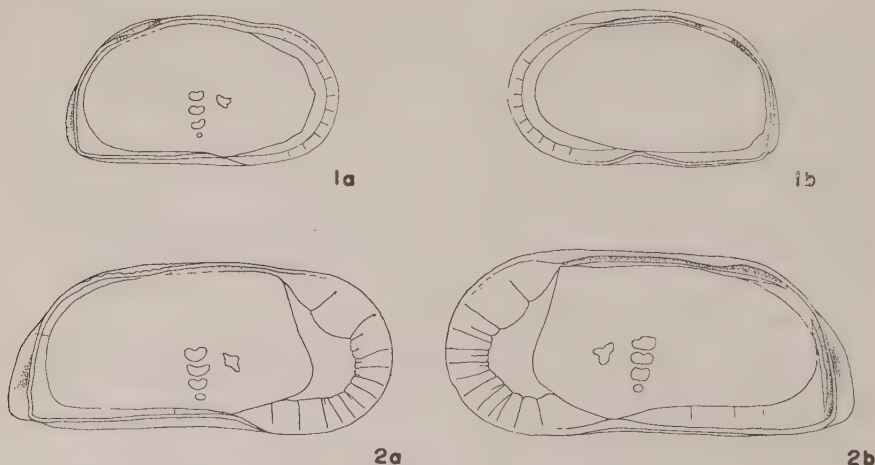
Text-figure 4B. Krithinae type pseudadont (Ontogeny and "Schalentropismus"). (×45)
a, left valve.   b, right valve.

1, 2. *Krithe sawanensis* HANAI, 1, young instar, 2, adult male, both from Pliocene Sawane formation, the cliff at Mano Bay, Sawane-machi, Sado-gun, Niigata Prefecture.

list from the selvage of the median element in the left valve. It differs from Bythocytherinae type lophodont by the presence of crenulation in the anterior and posterior hinge elements in some varieties. (Text-fig. 5)
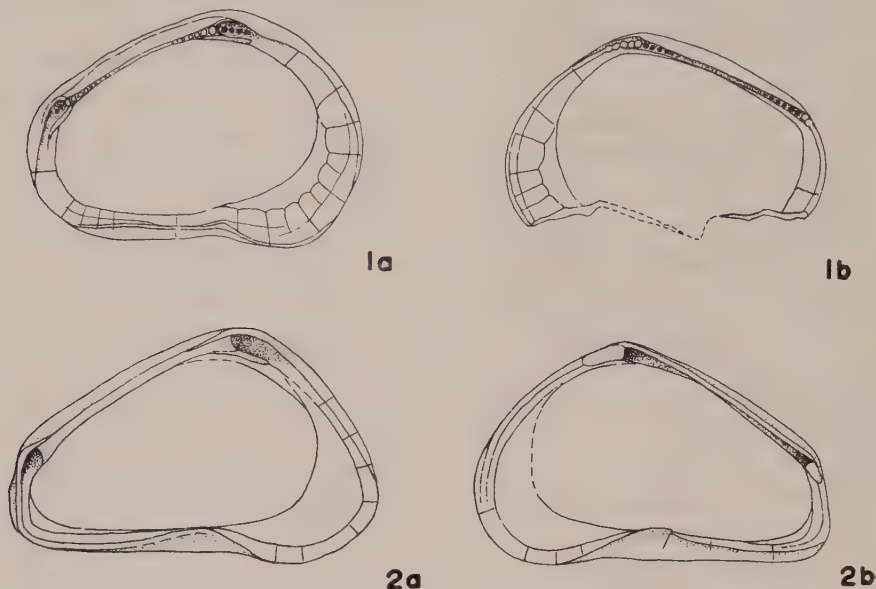
Text-figure 5. Eucytherinae type desmodont. (×89)
a, left valve.   b, right valve.

1. *Rotundracythere rotundra* (HORNIBROOK), from Soya station 5 of the Japanese Antarctic Expedition (68°15′ S, 33°37′ E, depth 495 m, Jan. 28, 1958).

2. New genus of Eucytherinae, from the same locality as fig. 1.

Pentodont or *Pectocytherinae type hingement:* see definition given by HANAI (1957) (p. 352). A characteristic tooth is formed at the anterior and posterior terminations of the median element in the left valve. These terminal teeth of the median element are composed of upper and lower elements. The upper element is an enlarged protrusion of terminal portions of the hinge bar which composes the main part of the median element. The lower element is a protrusion of the list in the inner (lower) side of the terminal portions of the median element. Sometimes the upper and lower elements fuse and form a tooth split horizontally. The main variations of pentodout are found at the terminal portions of the median element; that is, variation from hinge bar with obscure terminal teeth (e. g. *Arcacythere*), through terminal teeth with well developed upper elements and small or no lower elements (e. g. *Munseyella*) to those with well developed lower elements and smaller upper elements (e. g. *Pectocythere*). The characteristics of the median groove of the right valve of pentodont hingement are complementary to the above descriptions. (Text-fig. 6)

Pseudadont or *Krithinae type hingement:* see definition given by HANAI (1959) (p. 352). Young molt has a desmodont hinge. Selvage which formed the de-
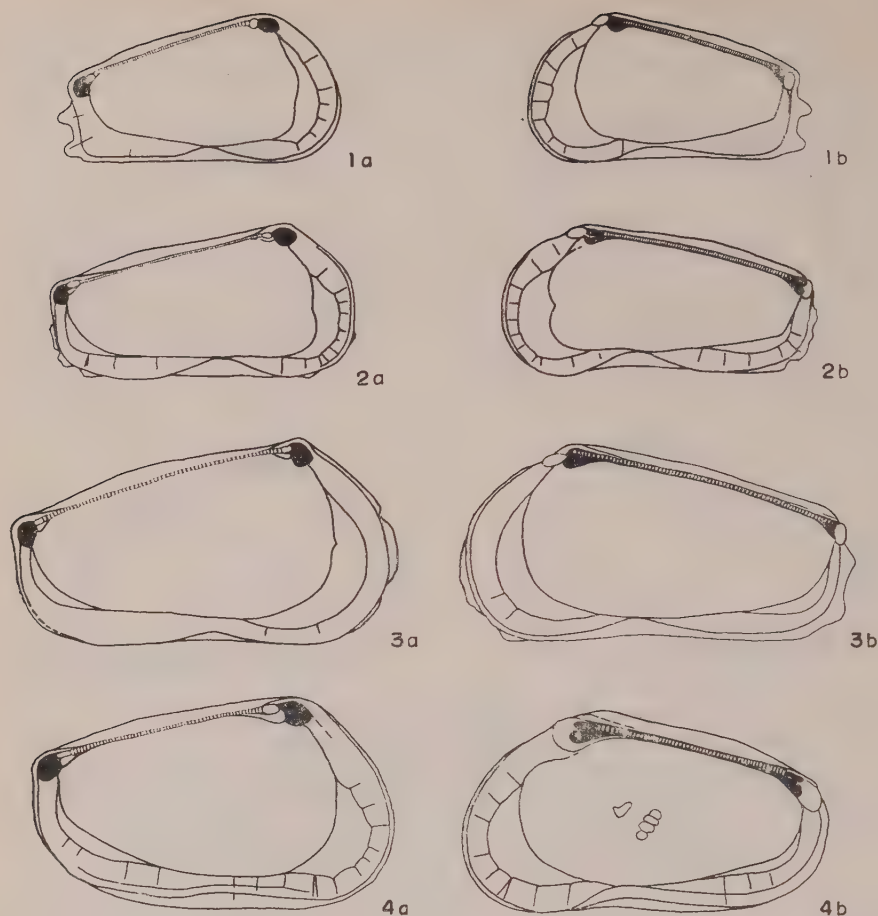
Text-figure 6. Pectocytherinae type pentodont. (×92)
a, left valve.   b, right valve.

1, 2.   *Munseyella japonica* (HANAI), 1, male, 2, female, both from Recent beach sand from the shore behind an imperial villa, Hayama-machi, Kanagawa Prefecture.

3.   *Munseyella hokkaidoana* (HANAI), from Pliocene Setana formation in the valley of Toshibetsugawa, about 800 mW of Omagari, Toshibetsu-mura, Setana-gun, Hokkaido.

4.   *Pectocythere quadrangulata* HANAI, from the same horizon and locality as fig. 3.

pressed middle element in the right valve of young molt becomes smooth or crenulate ridge with the same height as the terminal elements by the last molting, and connects both terminal elements. In the left valve, fused selvage and list which form the middle element in young shells are separted and become a smooth or crenulate groove connecting both terminal grooves. As a result variation from the young tripartite hinge with a distinctly crenulate middle element to adult hinge with obscured tripartite character is recognized.

Previously Ostracoda with desmodont and pseudadont hinges have been

included in subfamily Neocytherideidinae without further clarifying their relationship. HANAI (1959) pointed out that these two hinge types are ontogenetically close to each other, and therefore the *Krithe* group of pseudadont was classified as a group within the subfamily Neocytherideidinae. On the other hand, MANDELSTAM (1958) proposed a new subfamily Krithinae consisting of *Krithe* and its allies.

Dentition of this type ranges from Cretaceous to Recent. (Text-fig. 4A, B)

Adont: see definition given by HOWE and LAURENCICH (1958) (p. 348). There are at least three cases of adont formation. a) degenerated case such as encountered in the hingement of commensal forms (e. g. Entocytherinae) or in the hingement of forms living in subterranean water (e. g. Kliellinae). b) reverting case which is due to lose of specialization during the process of evolution such as encountered in some groups (e. g. some genera of Krithinae). c) "primitive" case with no specialization such as seen in primitive groups (e. g. Cytherellinae of Platycopa).

Merodont: see definition given by SYLVESTER-BRADLEY (1956) and HOWE and LAURENCICH (1958). These definitions cover the hinges of certain developmental stages of various lineages which are not related directly. HOWE and LAURENCICH (1958) subdivided merodont into paleomerodont, holomerodont, antimerodont and hemimerodont.

Xestoleberidinae type hinge: this hinge type varies from hemimerodont to antimerodont. The selvage strongly projects in the left valve and widely overlaps the right except for portions along the median element. The median element projects strongly in an arch with or over the selvage in dorsal view of the left valve. In the right valve, the anterior and posterior hinge elements are crenulate cusps projected in an arch over the flange. In the median element the selvage is depressed in arch-shape in dorsal view and sometimes the flange is projected as its outer wall. The dorsal contact line resembles a strongly recurved bow in dorsal view. (Text-fig. 7)

Cytherideidinae type hinge: in this type merodont, the selvage of the left valve is strongly developed along the dorsal margin of the hinge. This type of hinge varies horizontally from holosolenic holomerodont (e. g. *Haplocytheridea*) through hemisolenic antimerodout (e. g. *Clithrocytneridea*) and finally, by differentiation of the median element, to hemisolenic entomodont (e. g. *Cytheridea*). However, it differs from the merodont of Cytherinae or Cytheropterinae type in that the left valve is generally larger than the right valve along the dorsal margin or the former overlaps the latter. The anterior and posterior elements are wider than the median element, and show comb-like crenulation. The median element varies from distinctly crenulate to smooth.

Paracytherideidinae type hinge: this type is similar to Cytherideidinae type merodont, but is long and straight and is limited to antimerodont.

Eocytheropterinae type hinge: in this type of hingement, the tripartite character is not clear; thus the hingement shows an intermediate from between prionodont (or taxodont) and holomerodont. That is, the crenulations are comb-like instead of the pit-and-knob type. Differentiation of the terminal
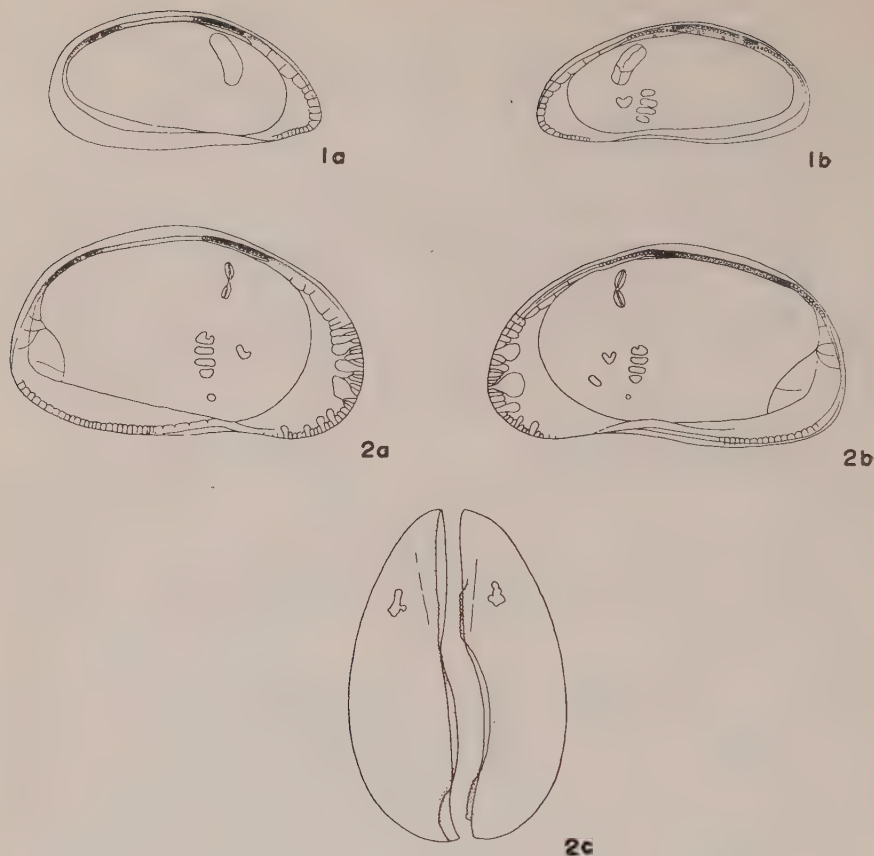
Text-figure 7. Xestoleberidinae type merodcnt. (×78)
a, left valve.   b, right valve.   c, dorsal view of both valves.
    1. *Microxestoleberis* sp., from Recent beach sand from the shore behind
an imperial villa, Hayama-machi, Kanagawa Prefecture.
    2. *Xestoleberis* sp., 2a, b, from Recent mud from Aburatsubo Cove,
Koajiro, Miurashi, Kanagawa Prefecture; 2c, from the same locality as
fig. 1.

elements is indistinct, because the intervals between crenulations are almost
constant.   However, the crenulations in the left valve are deepened and over-
hung greatly by the flange along the anterior and posterior portions of the
hingement, where the individual notch of the crenulations is more elongate
vertically than those of the median portion.   Right valve hingement is com-
plementary.   In this type of hingement, the overhanging flange above the
hinge element of the left valve causes the lapping of the left valve over the
right along the dorsal margin.
    Cytheropterinae type hinge: the dentition of this group is antimerodont.
In the right valve, a strongly developed flange overhangs the actual hinge
element but does not reach the terminal teeth, so as to form a furrow between
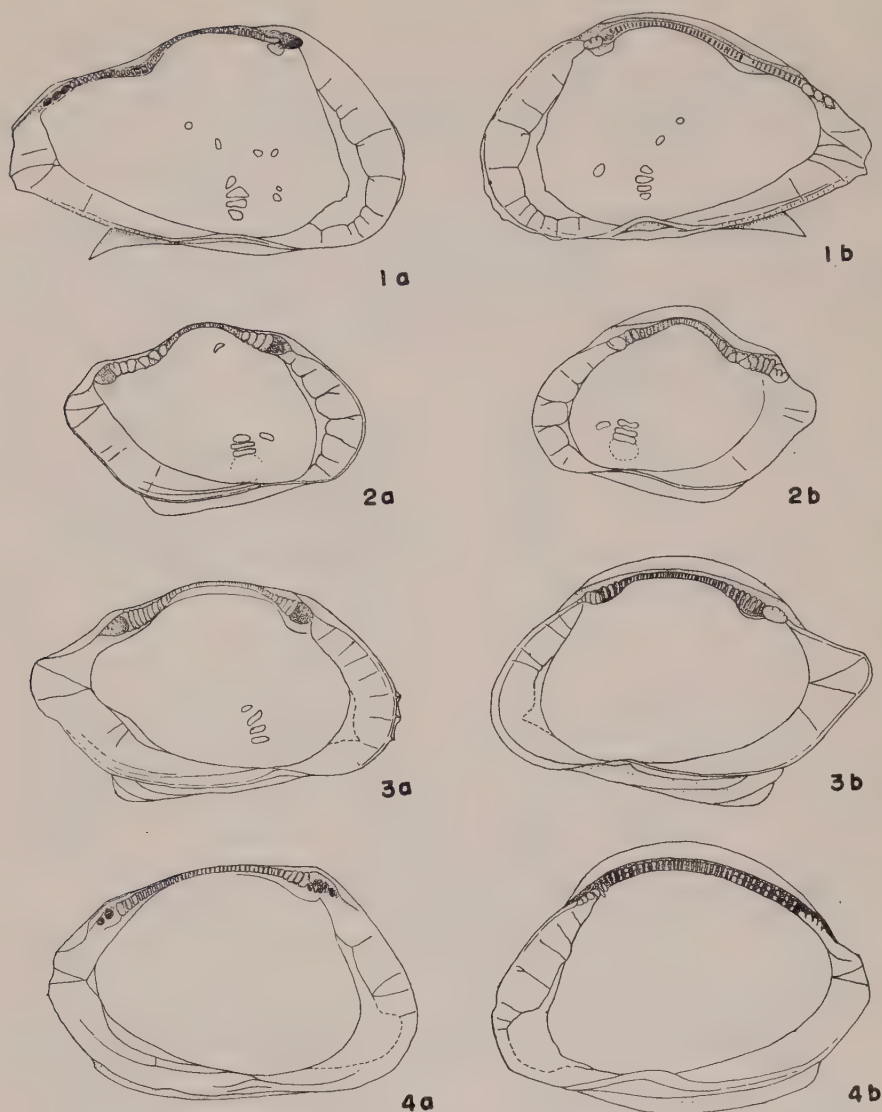
Text-figure 8. Cytheropterinae type merodont. (×79)
a, left valve.   b, right valve.

1. *Kobayashiina hyalinosa* HANAI, from Pliocene Sawane formation, the cliff at Mano Bay, Sawane-machi, Sado-gun, Niigata Prefecture.

2. *Cytheropteron miurense* HANAI, from Recent beach sand from the shore behind an imperial villa, Hayama-machi, Kanagawa Prefecture.

3. *Cytheropteron sawanense* HANAI, from the same horizon and locality as fig. 1.

4. *Cytheropteron uchioi* HANAI, from *Cucullaea* zone of the Pliocene Heki formation at a point W of Idenoue, Kawaminami-mura, Koyu-gun, Miyazaki Prefecture.

the terminal teeth and the overhanging flange. The outer wall of the termi-
nal sockets of the left valve fits into this furrow. In this type of hingement
the right valve overlaps the left valve along the dorsal margin. Each termi-
nal element varies from a series of knob-like teeth to a crenulate tooth plate,
and also these crenulations may fuse and form a knob-like tooth with some
incisions. These variations are mostly of the same degree in the anterior and
posterior elements.

In some genera (e.g. *Kobayashiina*), fusion of the crenulations is more
advanced in the anterior element than in the posterior element, and the groove
at the anterior termination of the median element deepens and the bar of the
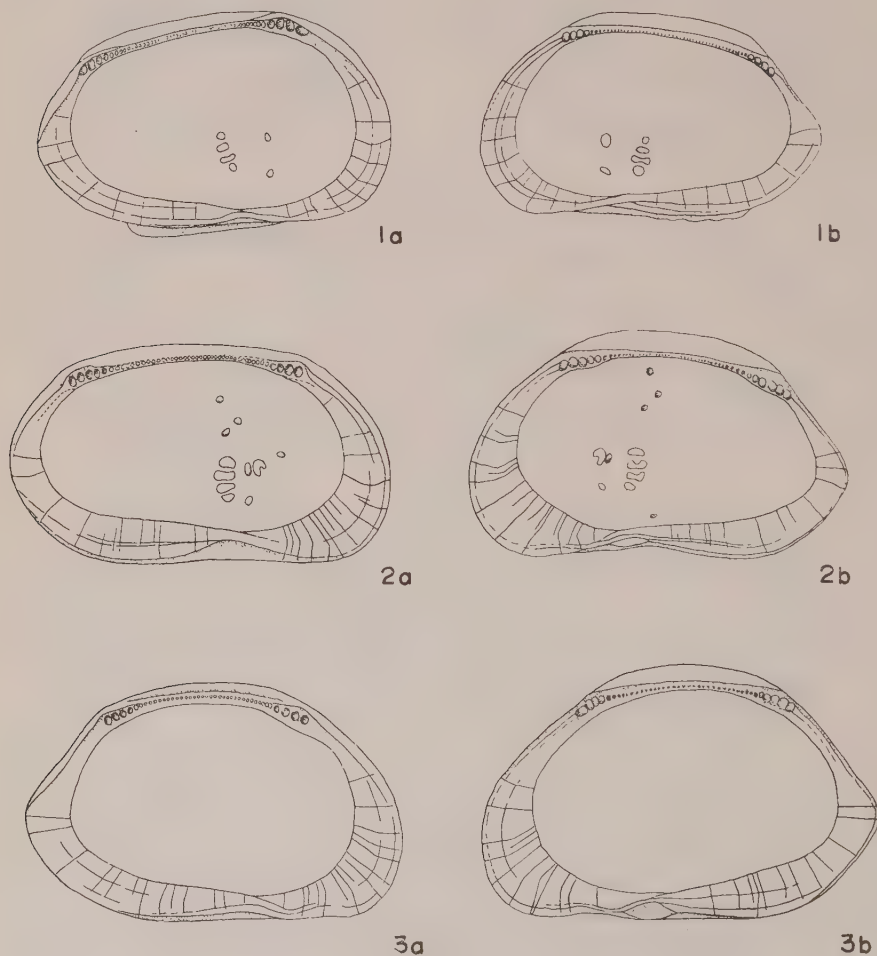
Text-figure 9. Cytherinae type merodont. (×69)
a, left valve.　　b, right valve.

1. *Loxocythere inflata* Hanai, from Pliocene Sawane formation, the cliff
at Mano Bay, Sawane-machi, Sado-gun, Niigata Prefecture.

2. *Cythere lutea uranipponica* Hanai, from the same horizon and locality
as fig. 1.

3. *Cythere japonica* Hanai, from the same horizon and locality as fig. 1

opposite valve protrudes to show a condition intermediate between antimero-
dont and schizodont.

The median element has comb-like crenulations. The hingement varies
from typical three folded antimerodont to a peculiar four folded hingement
by differentiation of the median element into a finely crenulate arched antero-
median element and a coarsely crenulate, more or less straight posteromedian
element. (Text-fig. 8)

Cytherinae type hinge: hinges of this group are antimerodont and have a
strongly developed flange in the right valve similar to Cytheropterinae type
merodont hingement. Each element show knob-and-pit type dentition. Median
element may vary contemporaneously from crenulate to smooth. (Text-fig. 9)
Entomodont: see definitions by SYLVESTER-BRADLEY (1956) and HOWE and
LAURENCICH (1958). As defined, the term entomodont refers to a certain de-
velopmental stage of hinge evolution and it therefore includes ostracod hinges
of several lineages. Detailed study of hinges, however, reveals defferences
between entomodonts of the different lineages.

Leptocytherinae type hinge: this type of entomodont hingement is grada-
tionally variable. The simplest hingement found in this type seems to be
merodont with a crenulate median element. A modification is found in *Cal-
listocythere* in which the dentition is entomodont. A further modification is
the diminution of the second anterior tooth and socket structure of the median
element. Still further modification occurs in the disappearance of the seg-
mentation and suppression of the crenulation of the median element of the
right valve and in the development of anti-slip teeth from the anterior teeth
of the median element of the left valve, as in *Leptocythere*. Finally, reduction
of anterior tooth and socket structure of both valves and development of a
strong anti-slip tooth in the left valve is characteristic of the *Tanella* type.

In this Leptocytherinae type of hingement, the right valve selvage forms
a ridge which is minutely socketed in its ventral half. This ridge fits into
the containant between the selvage and denticulate list of the left valve. This
characteristic differentiates the Leptocytherinae type from other entomodont
hingement. This type of hingement probably ranges from Jurassic to Recent.
(Text-fig. 10)

Other types of entomodont:

1) Quadrapartite hinges with a specialized type of median element appear
among the merodont hinges of Cytherideinae type (e. g. *Cytheridea, Cyprideis*).

2) It is possible with schizodont hinges that the two anterior teeth of
the median element do not fuse to form the split tooth characteristic of this
dentition, but with incomplete fusion assume the appearance of entomodont
dentition with large two teeth at anterior end of the median element (e. g.
Xenocythere).

3) Entomodont as defined by SYLVESTER-BRADLEY (1956) and HOWE and
LAURENCICH (1958) refers mainly to Progonocytherinae type hingement. This
phylogenetically very important subfamily is restricted to the Mesozoic and
is not so far known from Japan. Thus the writer has had no opportunity to
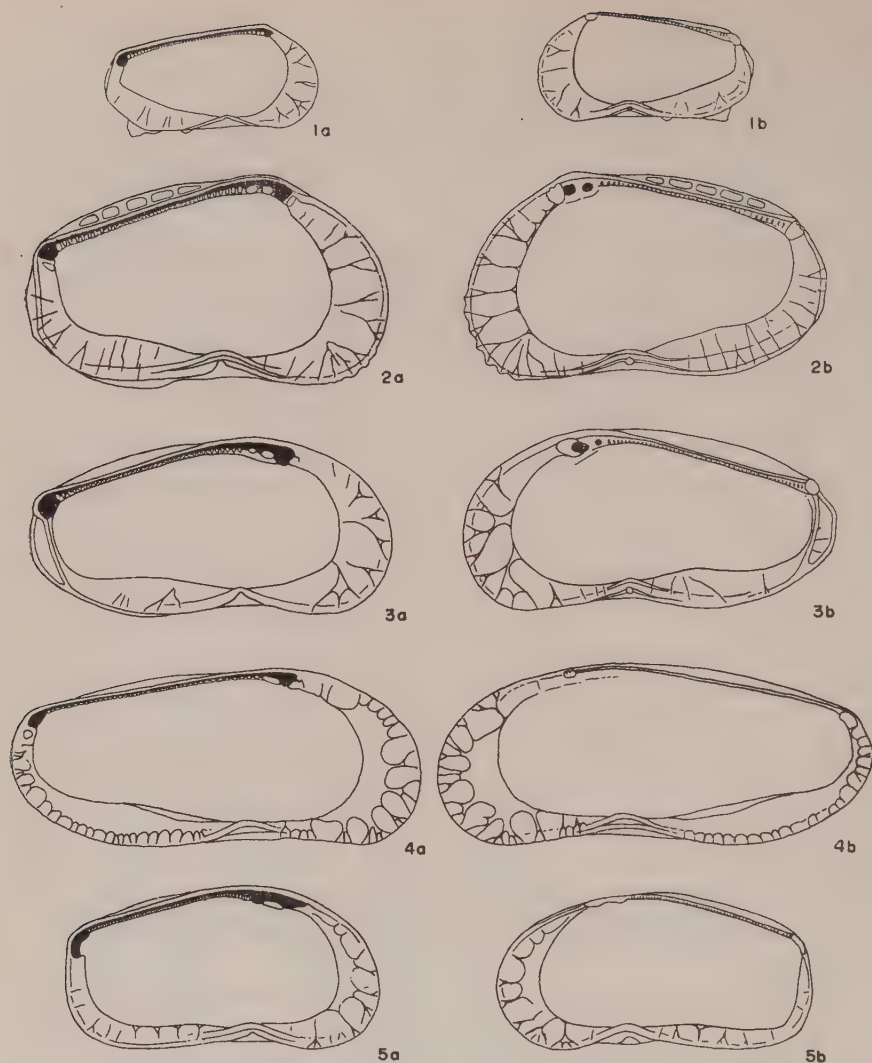
Text-figure 10. Leptocytherinae type entomodont. (×82)
a, left valve.   b, right valve.

1. *Callistocythere minor* Hanai, from Recent beach sand from Toura, Hamazaki-mura, Kamo-gun, Shizuoka Prefecture.

2. *Callistocythere nipponica* Hanai, from Recent beach sand from the shore behind an imperial villa, Hayama-machi, Kanagawa Prefecture.

3. *Callistocythere japonica* Hanai, from the same locality as fig. 2.

4. *Leptocythere pellucida* (Baird), from Recent deposit from Dog's Bay, County Galway, Ireland.

5. *Tanella miurensis* Hanai, from the same locality as fig. 2.

study this subfamily. Recently, Oertli (1957) and Triebel and Klingler (1959) recognized in Progonocytherinae a range of variation of the median hinge element from undivided type to subdivided entomodont.

Schizodont or *Schizocytherides type hinge*: see definitions given by Triebel

(1950), SYLVESTER-BRADLEY (1956) and HOWE and LAURENCICH (1958) (p. 349). These definitions are based on the bifid character of the anterior and antero-median hinge elements. The median element is always crenulate. The posterior element of schizodont hingement, however, displays contemporaneous variation. a) Schizodont with a lobed or crenulate posterior hinge element (e. g. *Paijenborchella*). b) Schizodont with a large round terminal tooth in the
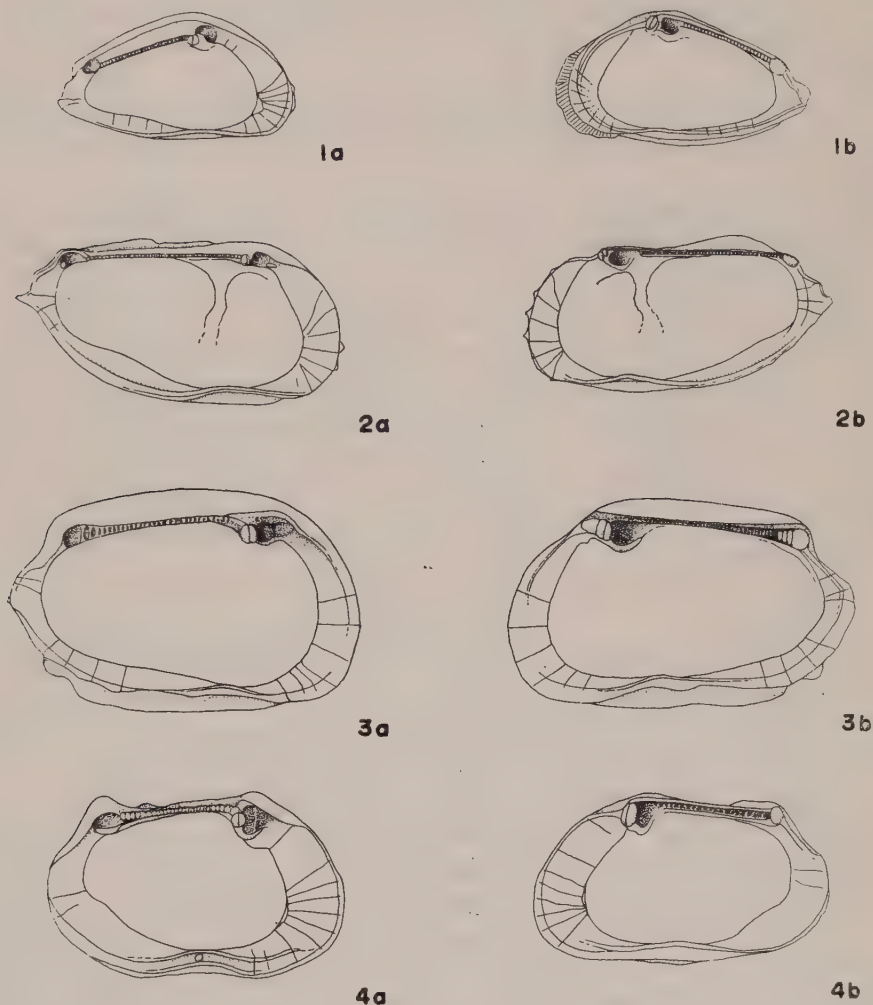
Text-figure 11. Schizocytherides type schizodont. (×73)
a, left valve.   b, right valve.

1. *Paijenborchella* sp., from Recent beach sand from the shore behind an imperial villa, Hayama-machi, Kanagawa Prefecture.
2. *Neomonoceratina microleticulate* KINGMA, from Pleistocene Sakurai silty sand, a cliff facing at the Tokyo Bay, Sakurai, Kisarazushi, Chiba Prefecture.
3. *Schizocythere kishinouyei* KAJIYAMA, from the same locality as fig. 1.
4. *Palmenella* sp., from Pliocene Setana formation, 800 m W of Omagari, Toshibetsu-mura, Setana-gun, Hokkaido.

posterior hinge element (e. g. *Schizocythere*).

Paijenborchellina may not be the direct ancestor of *Paijenborchella*, but at least it is not unreasonable to infer merodont similar to *Paijenborchellina* as the ancestral type of *Paijenborchella*-type schizodont. Young molt hingement of *Schizocythere* is almost identical to that of *Cnestocythere* and the posterior element of *Schizocythere*-type is more similar to that of *Cnestocythere*-type merodont than to that of *Palmenella*-type schizodont.

    c) The third type has a posterior tooth which is smooth and reniform. The corresponding socket has an auxiliary tooth in its ventral side (e. g. *Palmenella*).

    In this group, surface ornamentation shows wide variation, but the dentition is always schizodont and show rather narrowly restricted variation. (Text-fig. 11)

Gongylodont or *Loxoconchinae type hingement:* the term gongylodont was proposed by HOWE and LAURENCICH (1958) based on typical *Loxoconcha*-type hingement (see p. 351). It is possible to apply the original definition to the hinges of *Loxoconcha*, *Hirschmannia* and *Cytheromorpha*. In reality, however, gongylodont varies widely beyond the original definition. The posterior element of *Loxoconcha* sp. from Japan combines characteristics of hinges of *Loxoconcha* type and *Elofsonia* type. With consideration of the fact that differentiation of hingement is sometimes indicated by the downwardly arched terminals, it is possible to morphologically correlate the hingement of *Elofsonia*-type to even that of *Loxoconchella*-type. The series finally varies to adont *Phlyctocythere*.

    It can therefore be said that gongylodont hingement is tripartite; the anterior element is the positive ridge, the median element is the positive hinge bar and the posterior element is negative groove in one valve, elements of the opposite valve being complimentary. This ridge—hinge-bar—groove and groove—median-groove—ridge arrangement of the elements is the characteristic which differentiates gongylodont from all other types of hingement.

    All three elements of *Loxoconchella* are smooth, and the anterior and posterior elements of *Elofsonia* are crenulated. The nature of *Loxoconcha* type hingements is as follows: The denticles on the positive ridge become larger toward the distal end of the hingement and the indentation between the denticles simultaneously become large and finally form sockets. The enlarged denticles are connected at the dorsal side (Text-fig. 12, 5b). The smaller denticles are reduced and the two large outermost denticles become downturned claw around a large socket (see Text-fig. 12, 4b). In the negative groove, the sockets which form the crenulation become larger toward the distal end, and the projection between the sockets becomes larger simultaneously, forming a ball-like knob. The sockets are connected at the dorsal side (Text-fig. 12, 5a). Then the smaller sockets diminish and the two outermost large sockets form a horse-shoe shaped soket around the ball-like knob (Text-fig. 12, 4a). In the meantime, the median element changes from smooth to crenulate. There is considerable variation of the down-turned
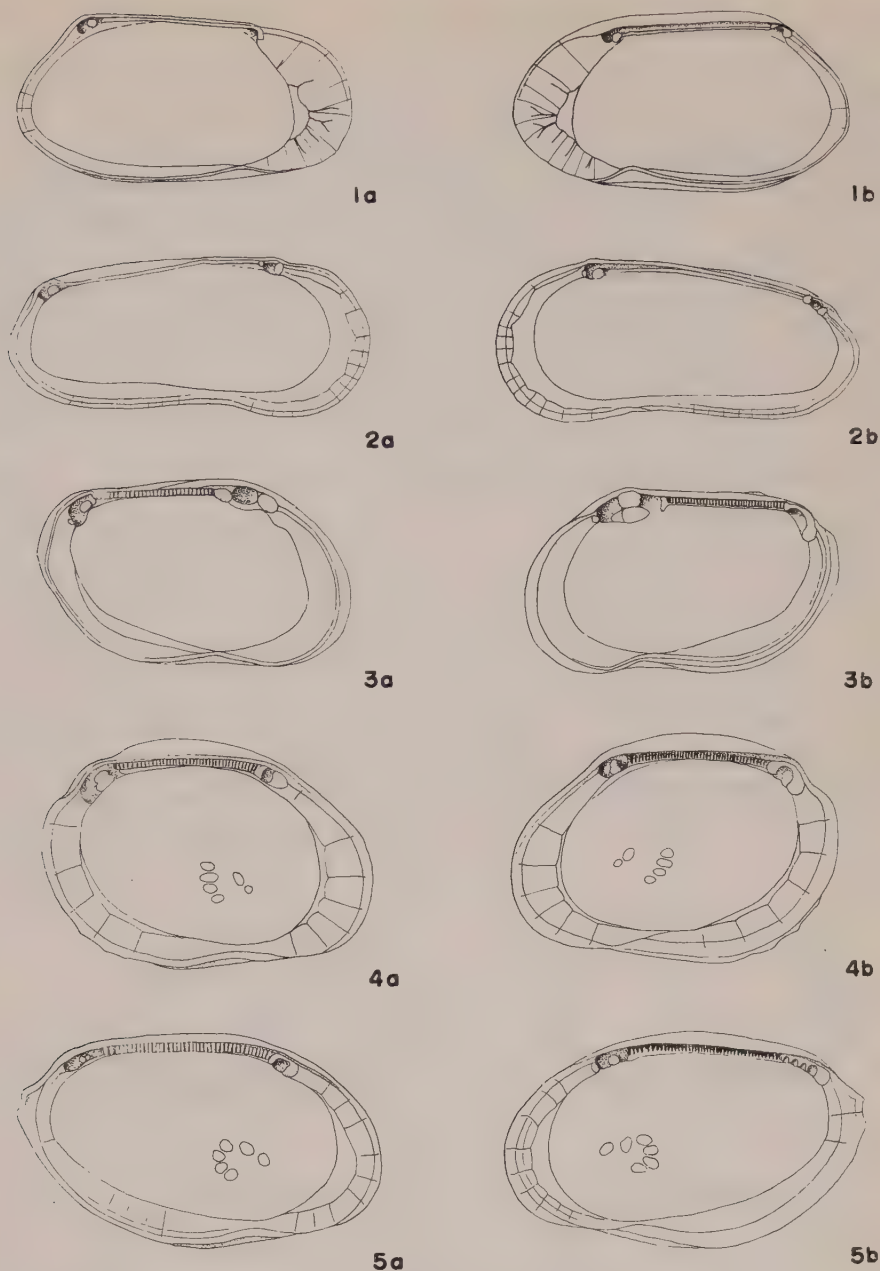
Text-figure 12. Loxoconchinae type gongylodont. (×73)
a, left valve.   b, right valve.

1. New genus of Loxoconchinae, from Recent mud from Aburatsubo Cove, Koajiro, Miura-shi, Kanagawa Prefecture.

2. *Cytheromorpha acupunctata* (BRADY), from Pleistocene Sakurai silty sand, the cliff facing at the Tokyo Bay, Sakurai, Kisarazu-shi, Chiba Prefecture.

3. *Loxoconcha* sp., from Recent beach sand from the shore behind an imperial villa, Hayama-machi, Kanagawa Prefecture.

4. *Loxoconcha* sp., from the same locality as fig. 3.

5. *Loxoconcha* sp., 5a, from Pliocene Setana formation, cliff along Isobetsu-gawa, about 700 m SW of Nakano-kawa station, Yubetsu-mura, Suttu-gun, Hokkaido; 5b, from Pliocene Setana formation, roadside cliff about 800 m SW of Nakano-sawa, Yubetsu-mura, Suttu-gun, Hokkaido.

claws and horse-shoe shaped sockets.

Smooth median elements are observed in Cretaceous *Loxoconcha* and finely crenulate one in Tertiary and Recent *Loxoconcha*. (Text-fig. 12)

Amphidont: see definitions given by SYLVESTER-BRADLEY (1956) and HOWE and LAURENCICH (1958) (p. 350). These definitions apply widely to the most developed stage of hinge evolution, and include the advanced hinge types of many lineages. This type of dentition is believed to be derived from hinges of Progonocytherinae, Protocytherinae and other entomodont or merodont types such as *Macrodentina* (*Polydentina*). HOWE and LAURENCICH (1958) subdivided amphidont into paramphidont, hemiamphidont and holamphidont. This subdivision can be said to be based on the concept of amphidont development and hinges of each developmental stage can sometimes be included in a single subfamily.

Hemicytherinae type hinge: the variations of Hemicytherinae type hingement were studied in detail by POKORNÝ (1955). Larvae have a hingement of archicytherid type antimerodont, which has higher distal ends in anterior and posterior elements. The most primitive type so far known is a species which was named "Hemicytherinae" genus ? *angulata* by SARS (1925) and WAGNER (1957). According to TRIEBEL and KLINGLER (1959) the hinge of this species is crenulate merodont and the species possesses a completely matured sexual organ in spite of its young or ancestral form hingement. Paramphidont and hemiamphidont hinges have not been found in the morphological series of this group. Hinges with remnant hemiamphidont character have a step-like anterior protogenic tooth with lower anterior half and higher posterior half.
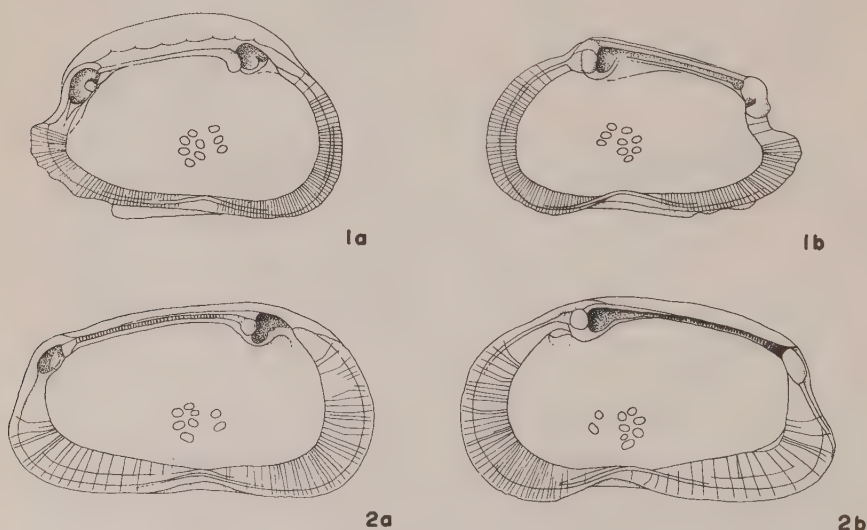
Text-figure 13. Hemicytherinae type amphidont. (×68)
a, left valve.   b, right valve.
1. *Mutilus* (*Mutilus*) sp., from Pliocene Setana formation roadside cliff about 800 m SW of Nakanosawa, Yubetsu-mura, Suttu-gun, Hokkaido.
2. *Hemicythere* sp., from the same horizon and locality as fig. 1.

Also traces of archicytherid crenulation remain in the posterior protogenic tooth (e. g. *Urocythereis*).

Holamphidont character becomes increasingly conspicuous in the series *Hemicythere-Elofsonia-Mutilus*. In *Mutilus* the anterior element of the right valve is a large, strongly protruded tooth with a round base, the step becoming obscure. The posterior element of the right valve is an elongate and non-crenulate tooth; its ventral wall has an incision in its middle. The opposite left valve has an auxiliary tooth in the ventral side of a socket corresponding to the incision of the right valve. The postero-median hinge element seems to vary from long and crenulated to short and obscurely crenulate. (Text-fig. 13)

Trachyleberidinae type hinge: the phylogeny of this hinge type was traced by Sylvester-Bradley (1948). This is a lineage which derived from middle Jurassic *Oligocythereis* with median hinge element sparated into two portions
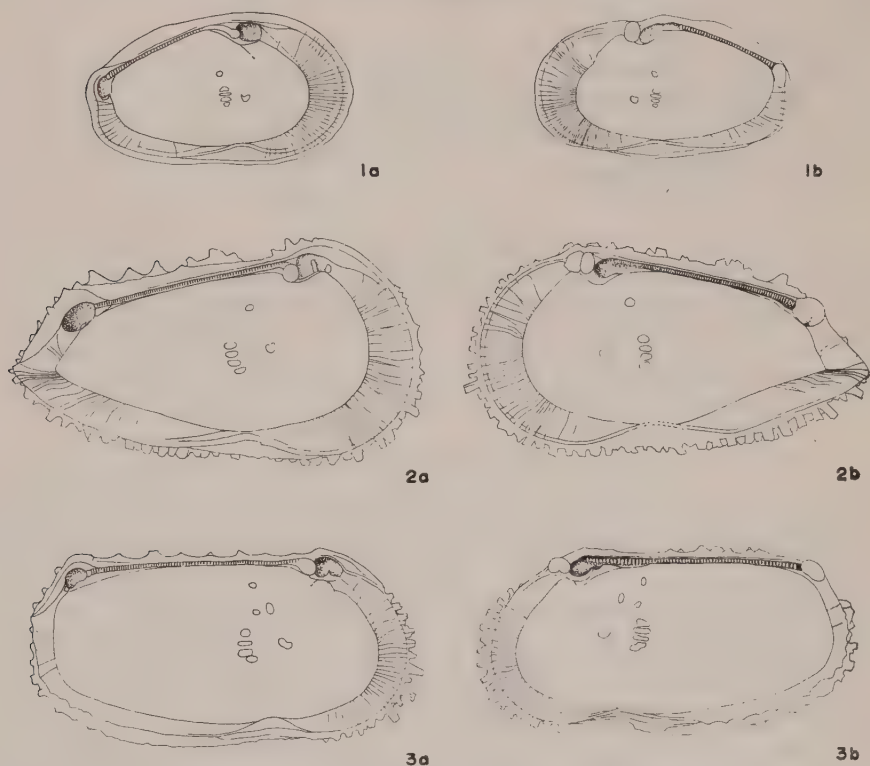
Text-figure 14. Trachyleberidinae type amphidont. (×56)
a, left valve.   b, right valve.

    1. *Buntonia* sp., from Pleistocene Katase formation, roadside cutting of road along the ridge 400 m NE of Ryukoji, Katase, Fujisawa-shi, Kanagawa Prefecture.

    2. *Trachyleberis scabrocuneata* (Brady), female, from Recent mud from Aburatsubo Cove, Koajiro, Miura-shi. Kanagawa Prefecture.

    3. *Echinocythereis* sp. (*Cythere darwini* of Brady, 1880), from the same locality of fig. 2.

and is followed through Cretaceous paramphidont *Cythereis* to Tertiary and Recent holamphidont *Trachyleberis*. Little is known of other lineages of trachyleberid Ostracoda. It is inferred from characters other than hingement that some lineages are mixed, but since their hinges show similar amphidont dentition, it is difficult to distinguish true lineages by hinge structure alone. The hinges of this group vary from paramphidont to holamphidont. Paramphidont predominates in the Cretaceous while Tertiary and Recent forms are hemiamphidont or holamphidont, the latter being especially dominant. (Text-fig. 14)

Brachycytherinae type hinge: this group is sometimes included in Trachyleberidinae (e. g. Pokorný, 1956, Triebel, 1958, Mandelstam, 1960) or is retricted to a very small group including *Brachycythere* and other closely related genera with paramphidont or hemiamphidont hinges similar to that of *Brachycythere* (e. g. Puri, 1957), or the subfamily may cover a considerably wider range of amphidont winged Ostracoda as originally proposed (e. g. Puri, 1953, Howe and Laurencich, 1958).

Cytherettinae type hinge: this group contains holamphidont hingement only. The posteromedian element varies from crenulate to smooth. The inner wall of the socket which forms the anteromedian element of right valve may be partially to entirely absent.

As variation progresses in holamphidont hingement, the inner wall of the socket in the right valve diminishes and the edge of the opposite valve is received in a groove at the upper part of the anteromedian tooth of the left valve. The anteromedian tooth does not have a corresponding socket in the opposite valve. Thus, it becomes an anti-slip tooth. In addition, the anteromedian tooth is isolated from the posteromedian bar (e. g. *Campilocythere*).

8. Conclusions

Hingement is an evolving feature and varies both vertically and horizontally. Therefore, taxonomic grouping should be based on discontinuities of a series arranged in accordance with the morphological similarity of the hinges. True relationship of Ostracoda can be inferred from such groupings (e. g. Leptocytherinae, Loxoconchinae). However, similar morphological differentiation may occur independently in unrelated branches of some groups (e. g. Trachyleberidinae, Hemicytherinae). On the other hand, if hinges differentiate more rapidly than other characters (e. g. *Macrodentina* group), relationship can not be inferred from the hinges alone. These are the limitations of applicability of hinge grouping to taxonomy.

Taxonomic evaluation of hingement beyond the above limitations should be derived from true relationships inferred from evaluation of various characters (e. g. Hemicytherinae). Hingement, as interpreted under the above concepts, does not vary widely within a genus or subgenus. There are, indeed, many cases of two or more closely related genera having the same type of hingement. A given range of hingement variation, delimited by coincident

gaps in various other characters as well as hingement, may be considered a genus or subfamily by a lumper and a subfamily or family by a splitter.

The groups of hinges thus conceived are delimited by more or less distinct morphological gaps. Although the range of variation differs within each group, the morphology is more or less continuous.

Similar morphological differentiation of two different branches can be recognized as a segment of continuous variation, as long as both do not vary identically within the same range. Even in cases where the hinges distinction is completely obscured in a certain vertical stage or in a certain part of an horizontal range of variation, the distinction can be quite clear in other stages or parts. The characters of hinges of each group recognized under the above concept have been described in chapter 7.

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TRIASSIC AND SOME OTHER OROGENIC SEDIMENTS OF THE AKIYOSHI CYCLE IN JAPAN, WITH SPECIAL REFERENCE TO THEIR EVOLUTION

By

Akira TOKUYAMA

(With Plates XV–XVIII)

Preface

It is in 1941 that Prof. KOBAYASHI has schematized the tectonic history of Japan in an excellent manner into the Permo-Triassic Akiyoshi, Jurasso-Cretaceous Sakawa and Tertiary Oyashima cycles of orogeny. During the past two decades stratigraphic data have been considerably amplified, especially on the sediments related to the Akiyoshi cycle. Since the three cycles of orogeny are distinct in her tectonic history, there are many kinds of orogenic sediments in Japan. It may be said that no sediments can be understood without considering the orogenic movements in Japan. Nevertheless, little has been done on the systematics of her orogenic sediments. The objective of this paper is to systematize the various kinds of orogenic sediments, concerning the Akiyoshi cycle, into five stages, namely the pre-, pro-, eu-, meta- and post-orogenic stages. The Akiyoshi cycle of orogeny is provided with the orogenic sediments of all the stages and reveals typical aspects.

At the outset I wish to express my sincere gratitude to Prof. Teiichi KOBAYASHI for his kind and continued encouragement, under whose guidance my geologic studies were commenced and this paper was prepared. I am also deeply indebted to Assist. Prof. Toshio KIMURA for the helpful suggestions and kind criticism in the field as well as laboratory works.

This paper occupies the main part of the Dissertation for the procurement of Doctor of Science, which was produced to the University in December 1960, and a part of which is already published as two following articles on the Japanese Journal of Geology and Geography, vol. 32 in 1961.

1. Entwicklungsgeschichte der orogenen Ablagerungen. *Japan. J. Geol. Geogr., vol. 32, no. 1*, pp. 85–110.
2. Late Triassic facies of Japan, *Ibid., no. 2*, pp. 279–292, pl. IX.

Contents

Introduction

Note on the five stages of development in an orogenic cycle

The Akiyoshi folded mountains were built up from the continental side of the Chichibu geosyncline in the middle and late Triassic epoch. It is of course one of the fundamental problems in 'Geology of Japan', when and how the geosyncline was created. In this paper, however, I do not intend to discuss the problem. It deals with orogenic sediments of the latest stage of the geosyncline and subsequent stages of the orogeny.

KOBAYASHI (1941, em. 1956) recognized three orogenic stages, namely pro-, eu- and meta-orogenic stages. In this paper the geosynclinal stage or the "mother stage" of orogeny, in which no distinct orogenic movements are introduced, is called pre-orogenic stage. The meta-orogenic stage is here divided into two stages: the meta- (s. s.) and the post-orogenic stages. In the former the folded mountains are elevated and completed, and the crust is yet strongly unstable, while in the latter the crust is already stable and the folded mountains tend to be destroyed. The meta-orogenic stage is characterized by "oronization", while so is the post-orogenic stage by "anoronization". Here an orogenic cycle is divided into 5 stages, namely *pre-*, *pro-*, *eu-*, *meta-*, and *post-orogenic* stages. These five stages are clearly impressed in orogenic sediments. The pre-orogenic sediments are those deposited in a geosyncline, when no significant "orogenic" movements were introduced. The prorogenic sediments are so-called Flysch-type sediments, which filled the "Saumsenke", when the embryonic folds or "Stammfaltungen" were taking place in the axis of the geosyncline. The eu- and meta-orogenic sediments include shooting sediments, which were derived from the elevating mountains into the fore-deep. The Alpine Molasse is a typical example of the meta-orogenic sediment. The post-orogenic sediments were deposited when the folded mountains were destroyed. The pro-, eu- and meta-orogenic sediments are those deposited, when the topographic relieves were strengthened, or in other words, they are products of "oronization", while the post-orogenic ones are those of "anoronization". Sediments of these four stages depend upon topographic relieves. On the other hand, the preorogenic sediments are the products before this stage. The "orogenic sediments" in common use include those of the later four stages, or those related to the topographic relieves. KRAUS (1926, 59) divided the orogenic cycle or his "Orokinetisches Zyklus" into two principal stages, namely the earlier deep orogenic stage or Tieforogen and the later high orogenic stages or Hochorogen. In this sense the orogenic sediments are products of the high orogenic stages, while the geosynclinal deposits represent the Tieforogen or the stage of the subterranean development.

As a rule the four stages are recognized in the history of the Alpine orogeny, which show a typical example of an orogenic cycle. They are the first geosynclinal stage, the second prorogenic or the Flysch stage, the third eu- and meta-orogenic or the Molasse and the last post-orogenic stage. The Cretaceous and early Tertiary " Flysch " are the sediments, when the first orogenic movements or " Stammfaltungen " have taken place in the Tethys geosyncline to divide the geosyncline into several " Saumsenke " in the axial and lateral parts of the geosyncline. Through the Cretaceous movements the axial zone of the Alpine folded mountains was completed. The third stage is characterized by " Molasse ", which was brought from the elevating mountains and deposited in the fore-deep or the Molasse-basin. After the culmination a depression took place in the axis of the mountains, where the Pleistocene post-orogenic sediments were deposited.

In the Chichibu geosyncline of Japan, embryonic movements of the Akiyoshi orogeny took place in the Carboniferous and subsequent stages. The Usuginu and Yasuba types of conglomerates containing exotic boulders are most extensive in the Middle Permian. They suggest an embryonic geanticline in the continental side of the geosyncline. The late Permian crustal movements are of special importance for the geosyncline. The contemporaneous Kuma series and allies in central Kyushu, Shikoku and Maizuru areas are the first orogenic sediments, which represent special conditions of the geosyncline. They reveal geanticlinal upfolding on the continental side and rapid subsidence on the Pacific side. These sediments resemble those of the " Wildflysch " in the Alps. At the same time an enclosed basin was formed in Kitakami region, in which thick and monotonous black shale of the Toyoma series was deposited. The Toyoma basin was a separated one, differentiated from the geosyncline. Thus the second type of the prorogenic sediments is represented by the Toyoma slate, which is almost barren of fossil except for trails called *Notaculites*. The third type of the prorogenic sediment is represented by the Skyto-Anisic Inai or Yakuno series in the Kitakami or Maizuru regions. The Inai series lies disconformably on the Toyoma slate, consisting of basal conglomerate and slate, intercalated by sandstone. Psephite and psammite of the series belong to the pure sandstone group, cemented by calcareous matter of chemical deposits. The shale is also calcareous and distinguished from the Toyoma slate, which the latter is of black mud facies; the Inai suggests clearer water than the Toyoma. As a whole the Inai is characterized by paucity of terrigenous matter. The Yakuno series in the Maizuru region overlies the Upper Permian Maizuru series, or the equivalent of the Kuma series, with slight disconformity. The Skytic stage of the series is characterized by graywacke and alternation of graded beds, similar to those in the subjacent Maizuru series. The rock facies passes upward into the Inai facies in the middle and upper formations of the series. The facies-change suggests the differentiation of the geosyncline into flysch basins.

As for the contemporaneous tectonic development of the periorogenic zone, little has been known, because the Skyto-Anisic formations are absent in the

zone except for a few localities in Kyushu and Shikoku.

The fundamental architecture of the core of the Akiyoshiiden appears to have been completed through the embryonic development of these ages. Subsequent orogenic sediments represent eu- and meta-orogenic stages, when strong relieves of folded mountains were built up ; a huge volume of coarse terrigenous materials produced in the mountain land was transported into the " molasse " basins of the intra-orogenic and further into the periorogenic zones.

The Ladinic Zohoin series and lower Atsu series contain " quartzoze sandstone " which is pelagic. The middle and lower Atsu series (upper Ladinic) contain fine sediments, occasionally intercalated by psephites and calcareous as well as siliceous deposits of the chemical precipitates. The psephites are produced not by the fluvial shooting but by a kind of bottom slumping. The " slide conglomerate " suggests strong subsidence of the basin instead of strong and steep geographic relieves. In these ages the relief of the mountains was not so strong as to issue voluminous terrigenous matters. They appeared first in the late Atsu age, when a thick series of rhythmic sediment, containing coal seams and fragments of the metamorphic complex, derived from the axis of the Akiyoshiiden, was deposited. Therefore it is evident that the Akiyoshi folded mountains became ragged in the Atsu epoch in West Japan. The lower Atsu series represents probably the stage of the " Frühmolasse " or the transition between the flysch and molasse, or between the subterranean and surface development of the Akiyoshiiden.

After the upfolding of the mountains in the Omine phase, a molasse basin was formed in the intraorogenic zone, where approximately 5000 m of the Mine series were deposited during the Carnic and earlier Noric ages. The Mine series contains rhythmic sediments of coal measures and thick conglomerate of alluvial fan or the like. They resemble the Rigi-type rhythms and the Nagelfluh of the Alpine Molasse. Numerous rhythms in the Mine series suggest the mechanism of the " mountain building " or oronization in these ages. They represent meta-orogenic sediments. Such frequent rhythms are not seen in the Noric Saragai and Shidaka series, although the latter contains several layers of fluvial boulder conglomerates, which were also derived from the axial zone of the folded mountains. Through the three stages of development, namely the Mine, Saragai and Shidaka, crustal movements or oronization in the folded mountains became weak. Another characteristic orogenic sediments are represented by the Liassic Kuruma series, which is a product of " an-oronization " along the axis of the folded mountains. The Kuruma basin was formed after the Rhaetic Toyogatake culmination, along the tectonic line between the metamorphosed and non-metamorphosed terrains of the Akiyoshiiden, called " Nagato tectonic line ", which was caused by the destruction of the axial core. The strong subsidence of the basin is indicated by approximately 10,000 meters' thickness of the Kuruma series inspite of the shortness of the Liassic age. Neither regular rhythm, nor shooting deposit is seen in the series, because it was a filling in the subsiding basin.

Thus three types of the prorogenic sediments, one of the euorogenic, one

of the metaorogenic sediments and three of the postorogenic sediments can be examined among the orogenic sediments of the Akiyoshi cycle.
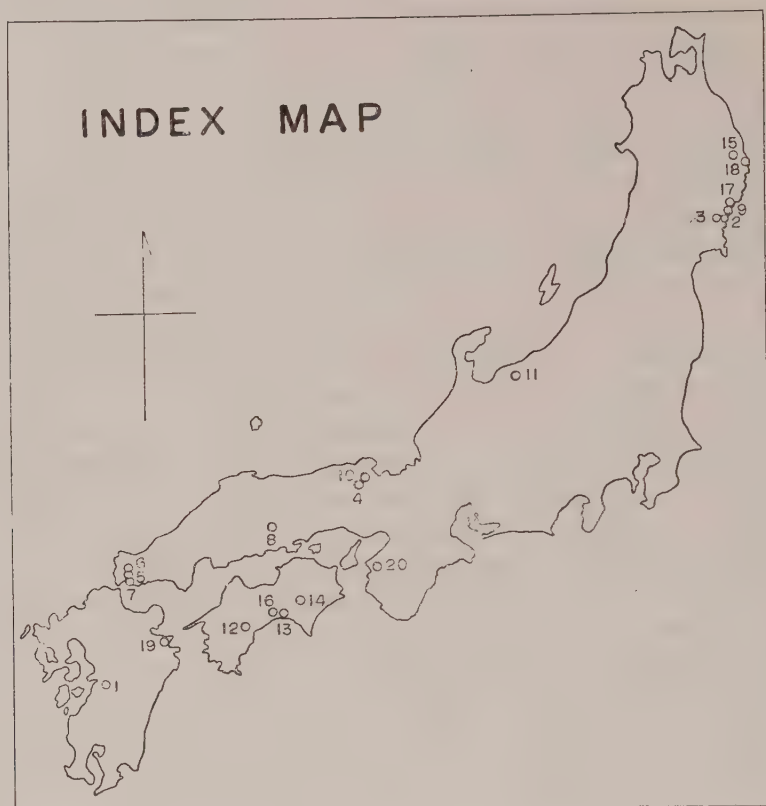
Figure 1. Index Map—Mesozoic orogenic sediments of Japan

stage	Akiyoshi cycle	Sakawa cycle
Vc	11: Kuruma (Liassic)	19: Onogawa, 20: Izumi (Upper Cretaceous)
Vb	10: Shidaka (Noric-Rhaetic)	
Va	9: Saragai (Noric)	18: Miyako (Aptio-Albian)
IV	6: Mine, 7: Asa, 8: Nariwa (Carnic-Noric)	(16: Ryoseki) (Neocomian)
III	5: Atsu (Ladinic)	17: Ofunato (Neocomian)
IIc	3: Inai, 4: Yakuno (Skyto-Anisic)	
IIb	2: Toyoma (Permian)	
IIa	1: Kuma (Permian)	14: Miyakodani, 15: Iwaizumi (Upper Jurassic)
I		13: Sambosan (Permo-Triassic) 12: Zohoin, (Ladinic) Kochigatani (Carnic)

I: Pre-orogenic, II: Prorogenic (flysh), III: Eu-orogenic (Frühmolasse), IV: Meta-orogenic (Molasse) and V: Post-orogenic sediments of the two cycles.

PART I
MINE & ATSU SERIES IN WEST JAPAN

A. Atsu series

The Atsu series (OZAWA, 1926) includes upper Ladinic sediments, which were deposited before the Omine phase of orogeny. The facies change of sediments between the pre- and post-Omine phase is so remarkable that the sediments are divided into two stratigraphic units, the Atsu (pre-Omine phase) and the Mine (post-Omine) series, although there is neither significant time break nor strong unconformity between them.

The Atsu series is 2000–2300 m thick and consists of the Zuiko, Kumano-kura and Enokawara formation in ascending order. Sediments are pure marine in the lower and middle stages, but paralic or non-marine in the upper stage. Terrigenous fragments are scarce in the lower two stages, but abruptly amplified in the upper stage. The lithologic change suggests that the geographic relief was insignificant in the lower two stages, but suddenly becomes distinct in the latest stage of the Atsu series. The Mine series after the Omine phase includes paralic and limnic sediments, indicates strong and wide geographic relieves, and represents the metaorogenic stage of the Akiyoshi cycle. Therefore the Atsu series represents the stage of "eu"-orogeny during which the geographic relief was formed. It corresponds to the "Frühmolasse" in the Alpine cycle.

1. General geology

The Atsu series is distributed around the Atsu area, in the shattered zone between the "Motoyama branch" of the Sangun metamorphic and the non-metamorphosed Yamaguchi terrain. It is strongly disturbed and intruded by large masses of granitic rocks. Its lower limit and stratigraphic relation to the subjacent beds are unknown. In the northern part it is overlain by the Mine series without strong unconformity.

The *Zuiko formation* includes siliceous limestone probably of the off-shore facies. The *Kumanokura formation* bears *Daonella-* and *Halobia*-shale in the lower and middle members and *Minetrigonia-Palaeopharus-Waagenoperna*-sandstone and *Lingula*-shale in the upper member. The *Enokawara formation* consists of epicyclic sediments, containing coal seams in the upper horizons. They are the oldest workable coal of Japan.

1.1. *Zuiko formation* (OZAWA, 1925; KOBAYASHI, 1948, 56; TOKUYAMA, 1958c)

It occurs as a patch between Atsu and Zuiko areas and is about 900 m thick. It is made up of a lenticular mass of limestone (attaining 500 m thick) and sandstone facies around the mass. They are replaced by sandstone and

GEOLOGIC MAP
OF ATSU AREA
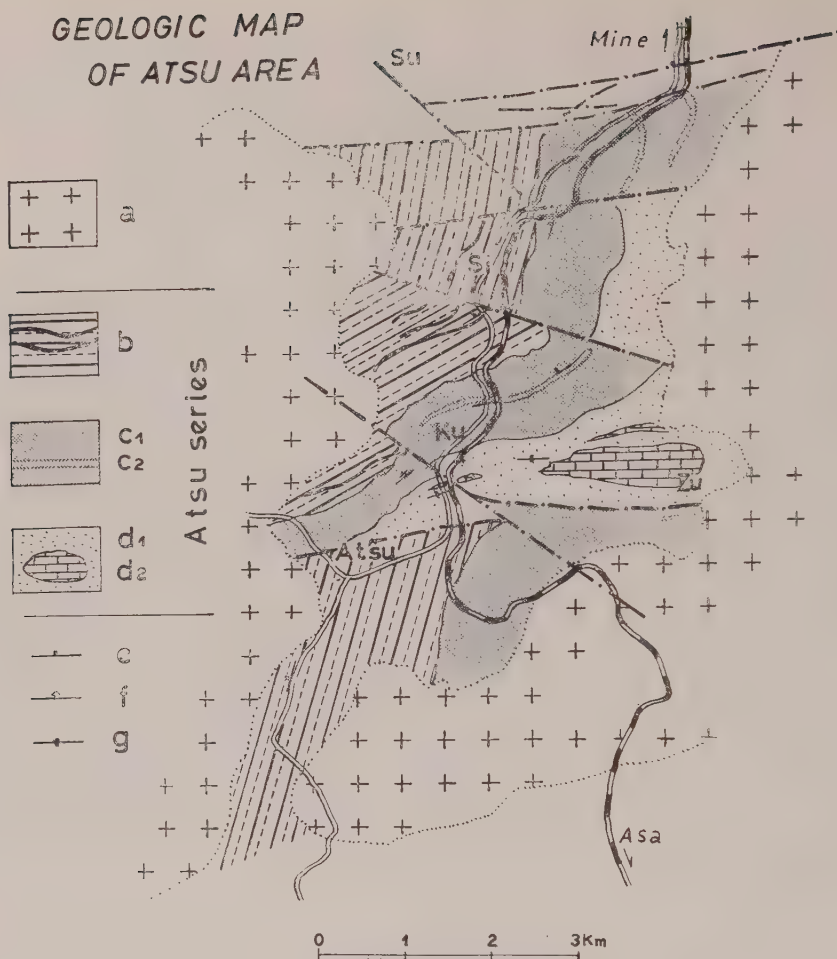
Figure 2. Geologic map of Atsu area.

a: granites, b–d: Atsu series, b: Enokawara formation (rhythmic beds of
coal measures), c_1: Kumanokura formation, c_2: *Daonella-Halobia* beds, d_1:
Zuiko formation, d_2: limestones, e: dipping 0–30°, f: 30–70°, g: 70 90°.
Ku: Kumanokura, Si: Shirogawara, Su: Sugiwara, Zu: Zuiko.

siliceous shale with small limestone lenses in the east. Because the formation
is bounded by faults, its base is not exposed. It is therefore unknown with
what facies the Atsu series began.

The basal part now exposed is characterized by medium and massive
sandstone with some conglomeratic and shaly layers. The middle member is
680–200 m thick. It includes a limestone lens, attaining 500 m in thickness at
Zuiko, but tonguing out suddenly to the east of Soto. The limestone lens
passes eastward into calcareous sandstone, which is replaced by massive and
quartzose sandstone at Atsu further to the east. The limestone is perfectly
recrystallized by the contact effect of porphyritic or granitic intrusion. The
upper member about 100 m thick, is characterized by massive sandstone with

intercalations of black shale. The insertions become numerous in the upper part.

Conglomerate of the lower member includes rounded pebbles of Palaeozoic cherts and shales. Sandstone of the formation is light coloured and quartz rich. It contains chert fragments and matrices of cryptocrystalline quartz or chert. They occupy 40% of the total volume. Shale fragements are less than 5%. Minerals are relatively well rounded and sorted; quartz/feldspar-ratio attains 3/1. The Zuiko sandstone is therefore characterized by high maturity. It is very similar to a sandstone of the Zohoin series of the Sakuradani area in composition and texture.

Since the limestone is completely recrystallized, the lithologic character of the Zuiko limestone is unknown, except for "crinoid stems", which were reported by Ozawa (1925). Near Atsu and Soto are small lenses of limestones, which are embedded in the siliceous shale. It is suggested that the limestone was deposited together with the siliceous shale; although a part of the siliceous shale depends upon the secondary silicification by igneous intrusion, but the main part was originally siliceous. Therefore the limestone is similar to the Sambosan limestone in lithology as Kobayashi (1931) noted. Quartzose and cherty sandstone of the formation supports an off-shore and relatively stable condition.

1.2. Kumanokura formation (Hase, 1947; Kobayashi, 1948, 56; Tokuyama, 1958c)

The Zuiko formation passes upward into the Kumanokura formation without any disturbance. The Kumanokura formation is 500 m–750 m thick and distributed around Kumanokura between Atsu and Minamiomine. Its lower and middle members are characterized by black shale, which is sometimes siliceous, sometimes more or less muddy and contains *Daonella*, *Halobia* and *Oxytoma*. Breccia-layers often inserted in the black shale, contain angular fragments of chert, shale and sandstone beside reworked pebbles of contemporaneous shale. The upper member is characterized by frequent alternation of sandstone and shale, containing *Minetrigonia*, *Palaeopharus* and *Waagenoperna* in sandstone and *Lingula* in a bituminous shale in the upper part. The change in bio- and litho-facies suggests that the basin became shallower in the later stage.

The lower member 350 m thick, is composed of alternating beds of sandstone, fine sandstone and shale, beside conglomerate intercalations. It is so to speak a transition between the Zuiko formation and shaly part of the Kumanokura formation. Here sandstone contains more numerous fragments of shale than the Zuiko sandstone. The conglomerate is better to say breccia, containing angular fragments of Palaeozoic black and grey shales and cemented by black siliceous shale and fine sandstone. It is sometimes a wedge in black shale and often provided with convolute beds in shaly parts. Angular phenoclasts of the conglomerate are embedded in the black shale, which the latter shows relatively deep and calm sea, because it is compact and somewhat

siliceous and rarely carries *Daonella* and *Halobia*. Therefore if there was no conglomeratic shooting, the basin was filled with black, compact and somewhat siliceous shale, and kept relatively stable condition. On the other hand convolute beds and aspects of psephites owe agitation of bottom by slumping. The conglomerate is related to subaqueous erosion rather than subaerial. Sandstone of the formation is provided with more shale fragments and less chert than the Zuiko sandstone.

The middle member is 230–250 m thick and consists of monotonous black shale, sometimes siliceous, sometimes a little bituminous and still in some other cases a little carbonaceous. It is on the whole characterized by massive and compact black shale, in which are scattered 2 species of *Halobia*, 1 *Daonella* and 1 *Oxytoma* beside *Anodontophora* (TOKUYAMA, 1959b). These shells are absent where the shale is compact and siliceous, and relatively common where it is more or less muddy.

Conglomerate or breccia layers are inserted in the lower part. They contain angular fragments of Palaeozoic shales, 1–2 cm in diameter, and suggest a bottom sliding or the like. HASE (1947, 51) considered disconformity at this horizon, because conglomerate layers are inserted. There is, however, neither break in succession, nor facies change between the sub- and superjacent beds. The conglomerate is a kind of intraformational conglomerate, indicating bottom slumping, rather than surface erosion. Rare occurrence of the Halobiidae and *Oxytoma* in the bed reveals an off-shore facies or a relatively deep sea. Since there is no remarkable facies change between the sub- and superjacent beds, it is obvious that the conglomerate was a subaqueous deposit. There is no evidence for strong geographic relief, although the conglomerate was accumulated in relatively unstable or agitated condition. The middle part of the member is characterized by relatively monotonous black shale, which often merges into fine sandstone. The monotonous shale is probably deposited in a relatively stable basin. Sandstone increases again towards the upper member, which is characterized by neritic alternating beds of sandstone, shale and mudstone. Sandstone of the horizon is more feldspathic than the Kumanokura and Zuiko sandstones. Sorting and rounding of the sandstone are relatively high. A remarkable fact is that the sandstone of this part contains rarely matrix, while that of subjacent beds carries siliceous shale and chert as matrix. A heavy mineral survey reveals that the sandstone received fragments from metamorphosed rocks beside granitic rocks, because amphibole is common among accessory minerals. This fact is very significant, because the provenance of the subjacent beds is considered to lie in non-metamorphosed terrain. The relief of the metamorphosed zone was begun to be emphasized as early as at this stage. The sea became shallower toward the upper member, seeing that the *Halobia-Daonella* fauna in the lower member merges upward into the *Minetrigonia-Cardinia* assemblage. *Halobia*, *Daonella* and *Oxytoma* are found in the shaly part, while *Minetrigonia*, *Palaeopharus* and *Waagenoperna* are contained in the sandy part. At Shirogawara, somewhat bituminous shale overlies the *Waagenoperna-Palaeopharus* bank and it contains *Lingula* sp. Along the high-

way between Shirogawara and Minamiomine crops out the following succession (in descending order):

```
1. 5 m : sandstone
0. 4   : bluish shale
5      : sandstone (coarse)
0. 2   : white shale
4      : sandstone
7      : conglomerate and sandstone
3      : conglomerate
thin   : shale
5      : sandstone
0. 5   : sandy shale
2      : conglomerate sandstone
20     : sandstone
2      : shale
?      : break
2      : conglomerate and sandstone (with no igneous rock)
15     : alternation of ss & sh (6–7 rhythms), contains Daonella in shales
5      : alt. ss & sh (sh>ss), single rhythm : 60–80 cm.
2      : feldspathic sandstone, containing Minetrigonia
2      : sh (0.5), ss (1) & cg. (0.5)
10     : alt. ss & sh (ss>sh), rhythm : 0.5–1 m.
0. 5   : Halobia shale, with 2 spp. of Halobia, 1 Oxytoma and 1 Daonella
3      : black f. ss, with 3 shaly layer (0.1–0.2 m)
2      : black shale
20     : massive sandstone
2      : shale
10     : sandstone with shaly intercalation
7      : hard shale
4      : sandstone
```

1.3. *Enokawara formation* (Tokuyama, 1958)

The Enokawara formation about 600 m thick, is made up of rhythmic strata, containing coarse sandstone, alternation of fine sandstone, shale and coaly deposits. It is distributed in wide areas from Shirogawara to Asa and has a relatively uniform succession.

It is an important fact that coarse sandstone contains numerous andesite fragments beside granitic and schistose rocks. It is quite similar to the Momonoki-Aso-sandstone of the Mine series in constituents and textures. The chief provenance was presumably in the axial zone of the Akiyoshi folded mountains. Coaly substances of the upper member reveal the large relief of the hinterland. It is therefore evident that the fundamental architecture of the Akiyoshi folded mountains was completed as early as the Enokawara stage, and this stage is characterized by the relief building of the hinterland. Coal seams of the formation suggest the increasing geographic relief.

The lower member is composed of alternating beds of sandstone and black shale, which the latter contains siliceous as well as andesitic matters. In the lower part of the alternation the shale is black and siliceous, like the Kuma-nokura-shale, but it is green in the upper part, because it received fragments of andesite as well as green schist from the elevating land. These fragments

in sandstone become more numerous in the upper horizon, so that the sandstone becomes similar to the Aso-Momonoki-type in constituents. Consequently the alternation merges into rhythmic sediments of the Momonoki or Yamanoi type. It is composed of two members, namely the coarse sandstone of the Aso type in the lower member and alternation of fine sandstone, mudstone and coal in the upper member. The thickness ratio of the two members is: ss/alt=1.5–1. The rhythmic bed bears relatively uniform lithology and persists horizontally, although coal is best developed in the middle part in the west of Kumanokura.

1.4. Correlation

The Atsu series contains marine pelecypods in the Kumanokura formation. *Daonella yoshimurai*, *Halobia subsedaka*, *H. atsuensis*, *Oxytoma atsuensis* beside *Anodontophora* sp. are found in the shaly beds (TOKUYAMA, 1959b) and *Minetrigonia katayamai*, *Waagenoperna* (=*Edentula*) *ozawai* and *Palaeopharus oblongatus* in sandy beds of the upper member (KOBAYASHI, 1935; TOK., 1960b). As already discussed in detail (KOBAYASHI, 1935; KOBAYASHI and TOKUYAMA, 1959) the *Daonella yoshimurai*-fauna is younger than *Daonella kotoi*-fauna of the Zohoin series, which the latter is correlated to the *D. lommeli*-zone or the Wengen formation of the Alpine Trias. Therefore the *yoshimurai*-zone is upper Ladinic, if not lower Carnic. On the other hand the two species of *Halobia* suggest the age earlier than the *Oxytoma-Mytilus* bed or the lower Kochigatani series, to which the upper Hirabara formation is correlated (TOK., 1957, 59b). *Halobia atsuensis* is somewhat related to *H.* aff. *molukkana* from the Neo-*Halobia*-bed (ICHIKAWA, 1954) of Itsukaichi area. It is a remarkable fact that *H. subsedaka* survived until the lower Hirabara stage (TOKUYAMA, 1960b, c). This means that no break exists in succession between the Atsu and Mine series. This agrees with the stratigraphic observation. *Minetrigonia katayamai* and *Palaeopharus oblongatus* are also common not only to the Kumanokura and Hirabara formations, but also to the lower Kochigatani series at Sakawa and Sakuradani. They are long ranged and extensive in the Upper Triassic of Japan. It is however, evident that the Atsu fauna is succeeded by the Hirabara one without break. It is noteworthy that the complete succession from upper Ladinic to lower Noric is obtained in Atsu and Mine areas of Nagato.

Oxytoma atsuensis and *Waagenoperna ozawai* are indigenous forms restricted to the Atsu series.

Since no marine shell is known of the Zuiko formation the age of the lower Atsu series is undetermined. The Zuiko limestone was once correlated to the Skytic Kurotaki-limestone (OZAWA, 1925) and Sambosan limestone (KOBAYASHI, 1935), but the two limestones are different from the Zuiko in age.

2. Tectonic history of the Atsu epoch

2.1. Three types of sediments in the Atsu series

The Atsu series is composed of three formations, each bearing its own lithologic character. The Zuiko formation is characterized by a limestone mass and

quartzose and cherty sandstones. The two kinds of sediments are similar to those in the Sambosan and outer periorogenic zones in southwest Japan, which suggest a very off-shore and relatively stable condition.

The Kumanokura formation is characterized by shale-rich sandstone, in which shale exceeds chert both in rock fragments and matrices, and breccia, indicating bottom sliding, besides the *Halobia-Daonella*-shale, which is some-times siliceous. The frequent sliding deposits are caused by unstability of the basin, but since no geographic relief was present in this stage, there is no supply of terrigenous matters. Therefore the sediments are monotonous, ex-cept for slide conglomerate. Subsidence of the basin or tilting of the bottom may be responsible for the sliding sediments.

Toward the later stage of the formation the basin became shallower, seeing that the fossil assemblage changes from the *Daonella-Halobia*-assemblage to *Minetrigonia-Palaeopharus.*

Sandstone of the upper part is arkosic and contains more fragments of granite and less of shale and chert than the subjacent beds.

The third sediment or the Enokawara formation is characterized by rhythms composed of Momonoki-Aso-type sandstone and coal seam-bearing alternation. The sandstone contains many fragments of andesite, porphyrite and granitic rock, beside schist, shale and chert. It is similar to the Momonoki and Aso sandstones in composition and texture. The rhythmic as well as coaly sediments suggest the elevation and relief of the hinterland.

Finally the three types of sediments are represented by three sandstones.

The *Zuiko sandstone* is quartzose and contains chert in fragments and matrix. The *Kumanokura sandstone* is characterized by shaly fragments in the lower and middle members, but by feldspathic sandstone in the upper member. The *Enokawara sandstone* is characterized by andesite, granite as well as schist fragments. The sandstone of the upper Kumanokura formation belongs to the Enokawara type, because it is supplied from the same proven-ance, although the Kumanokura sandstone is better agitated by currents.

The three types of sandstone are easily distinguishable from one another, because the Zuiko, Kumanokura and Enokawara sandstones are light coloured, dark and green respectively.

2.2. *Meaning of the three sediments*

The three sediments represent the provenances, palaeogeographic conditions and crustal movements which are different from one another.

The provenance of the Zuiko and Kumanokura formations was in the non-metamorphosed Palaeozoic area, which is actually distributed around the basin. The Upper Kumanokura and Enokawara formations contain granitic, schistose and volcanic rocks, which were derived from the axial zone of the Akiyoshi folded mountains. It is evident that the core of the Akiyoshiiden exposed in the latest Atsu age.

Palaeogeographically the Zuiko formation suggests water current and bathyal condition. The Kumanokura is related to a more stable condition of

crust than the Zuiko. Rare occurrences of *Daonella* and *Halobia* indicate re-
latively deep sea. In the later Kumanokura stage the basin became shallow,
because near-shore *Minetrigonia* sandstone as well as bituminous *Lingula* shale
appeared. Finally the Enokawara formation was deposited in a more closed
basin than the Kumanokura, seeing that coal seams are inserted in the upper
part. The coal measure may be a non-marine deposit, if not a limnic. The
Zuiko formation was accumulated under the stable condition of an open shelf,
because quartz sandstone reveals circulation of water. The Kumanokura indi-
cates a relatively unstable condition of the basin, for which either local sub-
sidence of the basin or tilting of the bottom may have been responsible. Up
to this stage the land-relief was absent or at least insignificant, because there
is no remarkable terrigenous material in this formation. Therefore the
" tiltings " or subsidences of the basin are considered to be expressions of the
phenomena of the " Tieforogen " of the Akiyoshi cycle. Toward the upper
member of the Kumanokura formation the basin became shallow and a land
with steep relief may have appeared on the sea. The Enokawara stage is
characterized by the increase of land relief, from which a great deal of ter-
rigenous material was derived. The last stage is characterized by shooting
of detritus from the elevating land.

The edifice of the Akiyoshi mountains was completed through the three
stages of Atsu series. The earlier half of the Atsu epoch represents the de-
velopment of the " deep-orogenic stage ", while the later half does the develop-
ment of topographic relief. Therefore the Atsu epoch is a transition from
the deep to high orogenic stages or from Tief- to Hochorogen by KRAUS (1926).
The lower two formations of the Atsu series display something like Flysch,
while the upper formation is somewhat Molasse-like. The difference between
the two types of sediments depends upon the difference between the two
conditions " before " and " after " the appearence of the ranged mountains.
The geographic relief was increased during the late Kumanokura and early
Enokawara ages.

In this sense the Atsu series corresponds to the " Frühmolasse " of the
Alps in the east Balkan region, which represents the transition between the
Flysch and Molasse (KRAUS, 1957)

B. Mine Series

The Mine series (KOBAYASHI, 1926) ranges from Carnic to earlier Noric
and represents the *metaorogenic sediments* of the Akiyoshi orogeny.

It is characterized by thick and coarse detritus which is either limnic
or paralic. They contain coarse fluviatile conglomerate and epicyclic deposits.
They are limnic and often associated with coaly shales. Among paralic sedi-
ments brackish *Anodontophora* bed, *Bakevelloides-Palaeopharus* bed which shows
embayment condition and *Minetrigonia*-sandstone which reveals coastal or near-
shore condition are enumerated. It is quite distinct from the contemporaneous
Nabae, Kochigatani and Togano series not only in thickness, coarseness and

sedimentary facies, but also in biofacies.

The Upper Triassic sediments bearing the above characteristics are distributed in Mine and Asa areas in Nagato, and Nariwa area and the adjacence in the Kibi-plateau. These are here referred to the Mine series (TOKUYAMA, 1960d).

The Mine series in Mine area (KOBAYASHI, 1926, KATAYAMA, 1938, HASE, 1951 and TOKUYAMA, 1958c & d) is 4800 m thick and ranges from lowest Carnic to lower Noric (TOK., 1957, 1959b). It is composed of brackish sediments of the Takiguchi formation, embayment sediments of the Hirabara formation, limnic Momonoki formation and the paralic Aso formation in ascending order, and marine fossils are found in the Hirabara and Aso formations.

The Mine series in Asa area (KOBAYASHI, et al., 1939, HASE, 1951) is 3000–5000 m thick and ranges from Carnic to Noric. It is made up of five formations; namely non-marine Takago conglomerate, limnic Kajiura formation (Akaiwa alternation and Idenoue delta), neritic Nakatsuka formation, non-marine Yamanoi formation and neritic Kamosho formation in ascending order, where marine bands are found in the Nakatsuka and Kamosho formations (KOBAYASHI, 1935, KOBAYASHI & AOTI, 1943, TOKUYAMA, 1959).

The Mine series in Nariwa region (KOBAYASHI et al., 1937, KOBAYASHI, 1938, TERAOKA, 1959, TOKUYAMA, 1960 d, e) ranges from middle Carnic to Noric. It is about 3000 m thick and consists of neritic Kyowa, limnic Mogamiyama, limnic Hinabata and neritic Jito formations in ascending order and marine fossils are found in Kyowa (NAKANO, 1957) and Jito formations (DIENER, 1915, KOBAYASHI & ICHIKAWA, 1952, NAKAZAWA, 1959, TOKUYAMA, 1960d).

The Mine series rests with a strong unconformity on Upper Palaeozoic rocks in the three areas. In Mine area it covers the steeply dipping Tsunemori series of the non-metamorphosed Yamaguchi group consisting of Permian shales and sandstones (fig. 3b). It overlies phyllitic and weakly metamorphosed rocks ·in the so-called Motoyama branch of the metamorphic Sangun group in ·Asa (fig.

A   B
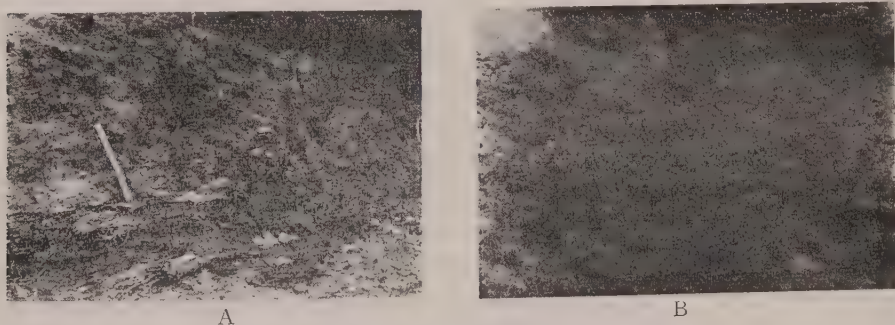
Figure 3. ·Basal unconformity of the Mine series.

A : Unconformity between the basal conglomerate (Takago conglomerate) and weakly metamorphosed rocks belonging to the " Motoyama branch of the Sangun group. At Go, Asa.

B : ·Unconformity between the Hirabara formation (low. Mine series) and steeply dipping Permian Tsunemori series. At Shiraiwa, Omine, Mine city.

3a) and Nariwa areas. Unconformities of the three areas represent a principal phase of the Akiyoshi orogeny, and the Mine series represents the metaorogenic stage of the Akiyoshi orogeny.

I. Mine series in Mine area

1. Stratigraphic outline

The Mine series in Mine area is 4800 m at the thickest and forms a broad syncline, opened southward, it is bounded by two faults in the east and west. The eastern boundary fault may have been active during the Mine epoch and marks the original boundary of the Mine basin. The Mine series abuts the Palaeozoic in the north along the fault. The western part of the Mine basin is bounded by a thrust, which is called "Nagato tectonic line" which marks off the southern front of the principal axial zone of the Akiyoshi folded mountains or the Sangun metamorphic zone. It includes (1) brackish sediments of the Takiguchi formation, including coal seams in the basal part, (2) embayment deposits of the Hirabara formation, yielding fossils of stagnant and agitated water of the embayment, (3) limnic Momonoki formation bearing coal and deltaic conglomerate and (4) paralic Aso formation consisting of coal measures and neritic shell beds.

The *Takiguchi formation* (max. 300 m) includes several coal seams near the basal conglomerate. This conglomerate found around Takiguchi area covers the Palaeozoic limestones. It is composed of angular blocks of limestones and their small fragments. Its irregular mode of accumulation suggests a kind of talus deposit. About 2–5 m above the conglomerate are shell banks, composed of a solitary species of *Anodontophora takiguchiensis* (1960b). The shell beds alternate with *Neocalamites* banks. They are overlain by relatively massive and monotonous sandstones with coal seams. Except for the plants and non-marine (probably brackish, if not limnic) shells, the Takiguchi formation contains no fossils.

The *Hirabara formation* (max. 1200 m) is a thick and coarse rhythmic sediment in an embayment (Palaeo-Hirabara bay). This formation consists of three rhythms of sediments, each being composed of a cycle, which is characterized by upward decrease of grain size. It is composed of the following 5 members: 1) breccias and coarse sandstone, 2) mudstone and shale, with marine shells and 3) bituminous sediments, 4) carbonaceous sandstone and mudstone, with coal seams and 5) alternation of sandstone and shale, sometimes fossiliferous (marine). During the Hirabara age sea invaded for three times. The transgressive facies are represented by three *Halobia*-shales inserted in the middle part of the first cycle, middle of the second and the top of the third. The first *Halobia* bed contains *H. subsedaka*, which is common in the middle Atsu series (Tok., 1959b, 1960b); the second bed carries *H. kashiwaiensis* and *H. kawadai*; the former is common to the *Oxytoma-Mytilus*-bed of the Kochigatani series, while so is the latter to the *Halobia-Tosapecten* bed of the middle Kochigatani series. The third also carries *kashiwaiensis* and *kawadai*; *kashiwai-*

ensis is more numerous than *kawadai* in the second *Halobia*-shale, while in the third, *kashiwaiensis* is less than *kawadai*. These three species of *Halobia* show the lower Carnic age of the Hirabara formation; middle and upper parts of the Hirabara formation are coeval to the lower Kochigatani series.

The Momonoki formation is on the whole limnic. It is composed of two coal measures and a bed of deltaic fanglomerate in the middle. There are two types of rhythms in this formation; i. e. the Mugikawa coal measures and Omine one. The rhythm of the Mugikawa type is a composite cycle, composed of two members; they are the lower conglomerate and coarse sandstones and the upper member of alternation, which consists of minor rhythms of fine sandstone, mudstone, coaly shale and coal. The Omine coal measures include several simple cycles, each consisting of conglomeratic sandstone, coarse arenite, thin and frequent alternation of mudstone and shale, coal and alternation of mudstone and shale in ascending order. In comparison with the two types of rhythms the Mugikawa one is thicker and more complicated than the Omine rhythm but the two are similar in constituents. Both of them consist of conglomerate and coarse arenite, mudstone, coaly shale and coal, all limnic. Each cycle seems to represent a stretch of shooting, followed by rapid upheaval of the hinterland.

The Aso formation consists of four members. They are brackish Inoki coal measures, neritic Mitsusugi sandstones, paralic Oda coal measures and paralic Sonose sandstone in ascending order. The *Inoki coal measures* are characterized by massive sandstone and several thin coal seams. The *Mitsusugi sandstone* is characterized by massive and monotonous sandstones in which several layers of mudstone or alternation of fine sandstone and shale are intercalated. These shaly and muddy insertions carry *Tosapecten* and suggest the condition of somewhat stagnant water. The *Oda coal measures* are composed of two symmetric cycles. Each cycle is made up of a transgressive hemicycle and a regressive hemicycle of the reverse order to the transgressive one. The transgressive hemicycle begins with coaly layers and is followed by brackish *Anodontophora* bed, *Tosapecten* sandstone and ended with *Eumorphotis* sandstone. The last represents the most off-shore facies of the Aso formation or opensea-facies, and therefore the inundation phase. The regressive hemicycle has a succession just reverse to the transgressive one. The inundation phase of the second cycle is represented by *Rhynchonella* shale instead of *Eumorphotis* sandstone. The *Sonose sandstone* is chiefly composed of massive sandstone in which coal seams, shell beds and *Rhynchonella* beds are intercalated irregularly. Rhynchonelloids of the Oda and Sonose formations are lower Noric in age (1957). The Carno-Noric pelecypod fauna of the Aso formation is indigenous; there is no other contemporaneous fauna in Japan (1960a).

Thus the Mine series ranges from lowest Carnic to lower Noric.

2. Takiguchi formation

The Takiguchi formation is the first sediment in the intermontane basin after the Omine phase of orogeny (KOBAYASHI, 1941), when steep and wide

land relieves were formed. It is distributed as a wedge in Takiguchi and Aigyo districts near Omine in Mine city and contacts Palaeozoic rocks to the east partly with unconformity and partly with fault. The formation begins with talus sediments along the limestone mass near Takiguchi, composed of angular blocks of limestone. They are non-stratified and irregularly accumulated. Since no effect of river or sea current is found in them, the breccia is probably terrestrial. It is restricted around limestone masses near Takiguchi and extremely local. The breccia is covered with a conglomerate bed, which contains chert and sandstone fragments beside large blocks of limestone and is cemented by sandstone. Therefore the conglomerate must be a subaqueous deposit. These two kinds of psephites were fillings of small depressions, covering their even surface. They are sometimes as thick as 50 m, but suddenly thin out laterally. Near Takiguchi there are *Anodontophora* banks just above the base ; they are composed of thin and frequent alternations of *Anodontophora*- and *Neocalamites*-banks which are brackish, if not limnic (1960, p. 190). They are followed by three layers of coal seams which abut Palaeozoic and Mesozoic rocks to the north and south. Sometimes the coal seam fills up fossil caves of the basal limestone in Takiguchi area. They carry sometimes silicified woods (*Dadoxylon*) of large trunks attaining 30–40 cm in diameter which owed the vegitation on the surrounding land. Coal seams are associated with thin shaly insertions, which include plant fossils. Coal measures of the formation, about 150 m thick, are characterized by relatively thin coal seams (0.5–1 m thick) and thick interspace of massive sandstone (20–30 m). They are similar to the Inoki coal measures or the lowest part of the Aso formation, not only in lithologic characters and sedimentary conditions, but also in the stratigraphic relations, because the Inoki and Takiguchi formations were deposited between limnic (subjacent) and marine (superjacent) beds. Above the coal measures comes a sequence of massive sandstone (max. 200 m thick). It is composed of monotonous and massive sandstones with a few insertions of conglomerates near the middle. The conglomerate includes fairly large boulders of sandstones and shales beside angular fragments of cherts from the surrounding Palaeozoic groups.

The Takiguchi formation was terrestrial at first and then limnic or brackish in the subsequent stage. The massive and monotonous sandstone bed was accumulated during the subsidence of the basin, because it is followed by marine sediments of the Hirabara formation. Similar massive sandstones and coal measures are found also in the Inoki coal measures, which are inserted between the limnic coal measures of the Momonoki formation and neritic Mitsusugi sandstone of the Aso formation. Therefore the massive sandstones and thin coal seams of the two formations suggest effects of subsidence in the sedimentary basin, and probably a brackish condition.

There is no index fossil suggesting the age of the Takiguchi formation, because it is barren of animal fossils except for *Anodontophora takiguchiensis* (1960, b, c), which is wide spread in the Mine series. It is evident, however, that the formation is either uppermost Ladinic or lowermost Carnic, because

the Takiguchi formation is included in the life range of *Halobia subsedaka*, which is common to the subjacent (middle Atsu series) and superjacent (lower Hirabara formation) beds (1959, 1960b).

Ozawa (1925) found *Cycadocarpidium swabii* Nathorst from a shaly bed at Ojigase, east of Takiguchi, which belongs to the Takiguchi formation. The plant fossil was considered an index of Rhaetic in Europe, but now its life range dates back to Ladino-Carnic in Takiguchi formation.

3. *Hirabara formation* (Katayama, 1938, Tokuyama, 1958c, d, 1960b)

It is composed of thick and coarse embayment sediments, made up of three cycles of sediments. Each cycle is about 350–450 m thick at the maximum. Beginning with coarse and angular psephites, it is succeeded by marine alternation of sandstone and shale in the middle and terminated with a coal seam or sometime with carbonaceous muddy sediments in the upper member (Tokuyama, 1960b).

3.1. *General geology*

The first cycle is thickest among the three, attaining 500 m. It is thickened in the south and thins out toward the north, where it abuts the Palaeozoic rocks. The lower member of the cycle or the psephites is 200 m thick, where psephites of sliding deposits are well represented. The middle member or the alternation of sandstone and shale is 120 m thick. Its lower part contains marine fossils, but its upper part includes coals. The coal is followed by the upper member or sandstone-rich alternation, 50–100 m thick, which sometimes contains marine fossils. Between the lower and middle members is intercalated a black shale bed, which carries *Halobia* and *Mysidioptera* and represents the transgressive facies.

The second cycle is not so thick as the first but represented by various lithologic and biologic facies (1960b, p. 191f.). Here the lower member or the psephites is 50–60 m thick, the middle member or the alternation is 200–150 m thick and the upper member is 50 m thick in the southern part. This cycle is somewhat more widely distributed than the first; the alternation of the second member abuts the Palaeozoic rocks directly at a locality 1 km to the east of Shiraiwa (Figure 3b).

In *the third cycle* the basin or the "Palaeo-Hirabara bay" was more expanded. Sediments of this cycle are on the whole characterized by *Minetrigonia*- sandstone, 350 m at the thickest. *Minetrigonia* is abundant in the middle member of the cycle. The member is occupied by alternation of massive and stratified sandstones, instead of mudstones and shales. The sandstones suggest a more opened basin than those of the middle member in the first and second cycles. Their grains are more rounded and sorted than those of the lower two cycles. Sandstones of the lower two cycles are characterized by angular fragments of rocks and bituminous matrix. The latter is absent in the *Minetrigonia* sandstone of the third cycle. In this cycle distinctions between the lower and middle members are not so apparent as in the second cycle, although

psephites are dominant in the lower member and disappear in the middle. The coarse deposits of the lower member pass gradually into the *Minetrigonia* sandstone of the middle member. The alternations of muddy sandstones and shales are found in the upper part, though they are thin. These alternations are sometimes carbonaceous, but no coal is found in the third cycle.

The upper member of the cycle is occupied by thick black shales of trans-gressive *Halobia* facies, attaining 120 m thick in the southern part of the Hira-bara basin. The *Halobia* shale is best developed here among the three cycles of the formation. It contains *Halobia*, *Oxytoma*, *Modiolus*, *Pleuronectites* and *Anodontophora* beside two " *Rhynchonella* " and a terebratuloid. *Halobia*, *Oxy-toma* and a " *Rhynchonella* " are common to the Kochigatani fauna in Shikoku (1957b, 1959b).

3.2. Sedimentary condition of the Hirabara formation

Palaeogeographically, the Hirabara formation is characterized by sediments of a small embayment, except for the three beds of *Halobia* shales, which indicate open sea environments. The Palaeo-Hirabara bay consists of 3 parts (1960b, text-figure) as follows :

A) *Northern 1/3–2/5* of the bay was occupied by stagnant water, in which bituminous sediments were accumulated. They are characterized by *Catinula-*, *Bakevelloides-* and *Palaeopharus-* banks in the fossil community and bituminous sediments in lithologic character.

B) *Central 1/3–1/5* of the bay was occupied by the slope of the basin between the northern shallower and southern deeper parts. There are found convolute beds and sliding sediments. The biofacies is characterized by ben-thonic communities of *Palaeocucullaea* (subgenus of *Parallelodon*), *Mytilus* and *Homomya*. Sediments are thickest and coarsest in this part.

C) *Southern 1/2–2/5* of the bay was covered with water current, which is suggested by sediments and fossils. Sandstone of the part is well rounded and sorted in the south, where exotic accessory minerals are found in sand-stones. Textures and constituents of sandstones suggest that the current was stronger in the southern than in the northern part. The biofacies of the part is represented by *Minetrigonia-*, *Pteria-* and *Cardinia-* banks. Except *Pteria okubatensis* the shells of the part are common to the Kochigatani fauna. It is interesting that the shells of stagnant water facies are common to the Na-bae-Heki fauna of the Maizuru zone, but the communities of the circulated water are common to those of the Kochigatani fauna.

The most off-shore facies of the Hirabara formation are represented by three *Halobia* shales, which are important in biostratigraphic correlations for wide distance, because most fossils of the beds are also common in the Kochi-gatani fauna. From south to north the fossil communities of the shale changes as follows : *Halobia Lima*, *Oxytoma—Modiolus*, *Pleuronectites—Rhynchonella*, *Ter-ebratula—Anodontophora*.

Tectonic activities of the Hirabara age are represented by the three cycles of sedimentation. The lower member of the cycle is characterized by irre-

gularly bedded sliding conglomerates, which owe to the steep slope between the northern and middle parts of the basin, caused by sudden subsidence of the centre of the basin (1960b, p. 187 f.). Therefore the lower member of the cycle seems to be characterized by rapid sediments of an embayment. The lower part of the member contains marine fossils, but they include coaly deposits in the upper. The change in bio- and litho-facies suggests that the basin became shallower in the later stage. The middle stage of the cycle is characterized by filling of the subsiding basin, because the alternation of so-called graded bedding types are predominant in this member. In this stage basin filling exceeded the subsidence or the subsidence was so weakened that the basin was filled up.

Towards the upper part the basin seems to subside once more, seeing that some marine fossils occur in the superjacent beds of the coal. The second cycle begins with renewal of rapid and sudden subsidence of the basin. As the result the basin became wider at this time than before. Then subsidence recurred in the third cycle. The basin was further widened in the third cycle. This is suggested not only by the distribution of sediments (fig. 7), but also by the lithology of sediments. Sandstones of the third cycle are characterized by *Minetrigonia* sandstone, which show a wide and open condition than the incised embayment of the first and second cycles. The final stage of the Hirabara formation is marked by thick and monotonous black shales of
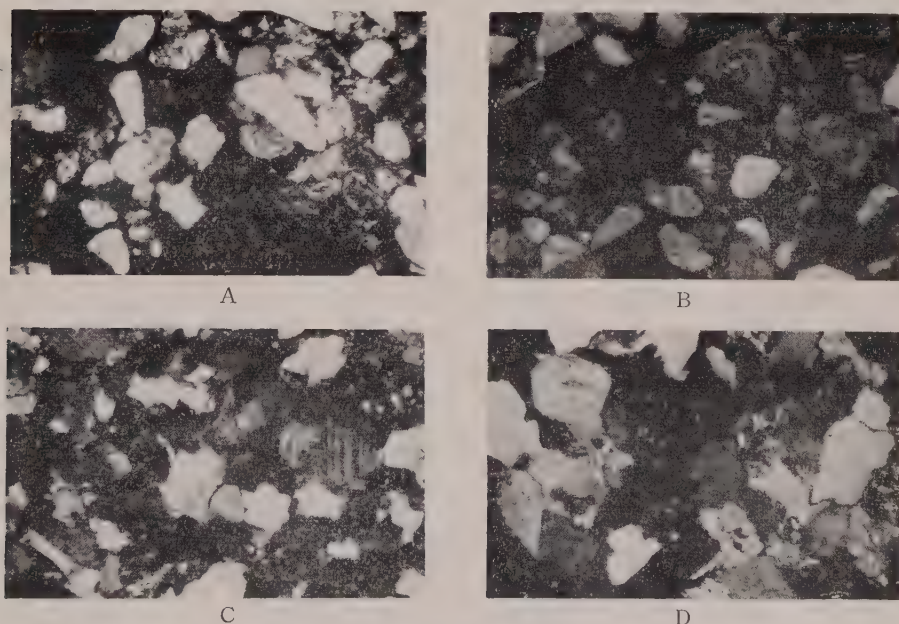
Figure 5. Sandstone of the Hirabara formation

A: Sandstone of B-facies of the 2nd cycle, at Hirabarazaka.
B: Sandstone of A-facies of the 2nd cycle, at Shiraiwa.
C: Sandstone of C-facies of the 2nd cycle, at Shirogawara.
D: *Minetrigonia* sandstone of the 3rd cycle near Okubata.

Halobia-facies suggesting marine invasion.

Finally, sediments of the Hirabara formation were transported from the surrounding regions of the basin, which were occupied by the non-metamorphosed Palaeozoic rocks or the Yamaguchi group. Neither igneous nor metamorphic rocks are found in the psephites and psammites of the formation. Most of quartz and feldspars in sandstones were probably reworked from Palaeozoic sandstones, because they are sometimes well rounded and constituents of sandstones show a fairly high maturity, notwithstanding the fact that the water of the basin was almost stagnant. Studies on heavy minerals suggest that the Hirabara sandstones are different from the Momonoki and Aso sandstones in origin; minerals of the latter two formations were originated in the granitic rocks of the axial zone of the Akiyoshi folded mountains and transported by rivers. In this formation, however, sediments were supplied from the surroundings of the basin, where Palaeozoic rocks were exposed.

4. *Momonoki formation* (KATAYAMA, 1938; em. TOKUYAMA, 1958 c, d)

The Momonoki formation which is made up of deltaic sediments and limnic coal-bearing beds, consists of the Mugikawa coal measures, the Momonoki delta and the Omine coal measures in ascending order. It is characterized by fluviatile or shooting sediments (Flußschotter) transported from the elevating hinterland.

The facies change between the Hirabara and Momonoki formations is remarkable, although there is no remarkable clino-unconformity between them. The Hirabara formation is, as explained above, a filling of an embayment and received its materials mainly from the Yamaguchi group, while the Momonoki is composed of limnic and fluvial sediments, supplied from axial region of the Akiyoshi mountains. The difference between the two formations is explained not only by the palaeogeographic conditions, but also by the tectonic movements of the two stages.

4.1. *Mugikawa coal measures* (TOKUYAMA, 1958c)

The Mugikawa coal measures are composed of 3 composite cycles; thickest parts of the three cycles are 90 m, 150 m and 125 m thick in ascending order. Each cycle is made up of 2 members: the lower member is composed of conglomeratic sandstone and very coarse sandstone of fluvial sediment; the upper member is composed of about 10 small rhythms, consisting of fine sandstone, mudstone or alternation of sandstone and mudstone, coal and coaly shales. The lower member or coarse sandstone is thicker and much widely distributed than the upper member or rhythms of fine sandstones and shales. It is thickest in the middle part of the basin and thins out to the north and south. Coaly sediments disappear at the both ends. Coal seams of the formation are sometimes thick, but suddenly they thin out laterally in part. The thickest part of coal varies among beds, and its thickness and quality are variable. Plant fossils are common in the shaly part, and sometimes drift woods are found in the sandy part.

4.2. *Momonoki delta* (TOKUYAMA, 1958)

It is composed of two members. One represents the delta facies or the fore-set bed and the other the beach or lateral facies. The first includes the muddy top-set and fanglomeratic fore-set beds. Cross-beddings of the fore-set beds (Pl. XV, figs. 1, 2) depend upon a steep subaqueous slope, on which they were deposited. The lateral or beach facies includes bottom-set beds and those deposited in the sides or lateral parts of the fore-set beds. It is characterized by a well sorted and stratified conglomerate (Pl. I, fig. 3) and bears coaly shales, inserted in the middle (Pl. XV, fig. 4). The Momonoki delta includes two fore-set beds. The lower one is thicker and more widely distributed than the upper one. The two conglomerate layers are thick in the southern part and 300 m and 150 m thick at Sugiwara respectively, but thin out to the north of Fujiyakochi (about 7 km to the north of Sugiwara), where they are replaced by conglomerate of the lateral facies. Cross-bedding of the fore-set beds suggests the direction of transportation, or stream direction, to be NNW to SSE. This stream-direction shows the direction of provenance of the sediments in the Momonoki stage.

The conglomerate of the lateral facies is found as thin insertions of coaly as well as muddy layers. They are, though thin, distributed in wide areas to the north of Shiraiwa. Near Ofuku, about 10 km to the north of Omine, the coaly beds attain 2 m thick. The bottom-set beds of the delta are distributed near Shirogawara to the south of Sugiwara. It is similar to the lateral facies in constituents, consisting of thin coals and stratified conglomerates.

Constituents of conglomerates are polygenetic, composed of round pebbles of porphyrite, granitic rocks (gneiss and granite) and crystalline schists besides non-metamorphosed Palaeozoic rocks, such as chert, shale and sandstones. These rocks are also found in the rock fragments of sandstones or matrices of conglomerate, although volume-ratio of constituents is different between conglomerates and sandstones. Andesites, schists, Palaeozoic cherts and shales besides fragments of granitic rocks are enumerated among the constituents of sandstones (1958). Therefore sandstones of the formation are derived from the same provenance as conglomerate.

Since the base of the Mine basin is composed of non-metamorphozed rocks of the Palaeozoic Yamaguchi group, none of granitic rocks, crystalline schists and andesites (trachytic andesite) are found actually around the basin. Cross-bedding of the fore-set bed, however, suggests that the provenance lies in the NW side of the basin. It is evident that the metamorphic, andesitic and granitic rocks were transported from northwest beyond the non-metamorphosed zone of the Yamaguchi terrain. It is suggested that these crystalline rocks were derived from the axial core of the Akiyoshi mountains, because they are identical to the metamorphic rocks of the Sangun and Hida groups. The western boundary of the Mine series is marked by the Nagato tectonic line, which is considered as the front of the Akiyoshiiden (KOBAYASHI, 1952, KIMURA, 1960), to the west of which the Sangun metamorphic rocks were distributed. Granitic rocks found in conglomerate and sandstone of the Momo-

noki formation are similar to the so-called "Funatsu-granite" in mineral com-
position. They include microcline, orthoclase and albitic plagioclase, beside
numerous dusty inclusions in quartz and feldspars. The Funatsu granite is
characteristic of the zone along the "median tectonic line in the inner zone"
(KOBAYASHI, 1952), which is the boundary between the plio- and mio-magmatic
zones of the Akiyoshiiden. Thus the *provenance of the Momonoki formation*
lies probably in the zone along the "median tectonic line of the inner zone"
or the axial core of the Akiyoshiiden, which may have been distributed fur-
ther to the northwest of the Nagato tectonic line.

4.3. *The Omine coal measures* (TOKUYAMA, 1958c)

The Omine coal measures are composed of 6 simple rhythms, each con-
sisting of (1) conglomeratic sandstone and coarse arenite, (2) mudstone or
alternation of fine sandstone and mudstone, (3) coal seam and (4) mudstone or
shale. Each rhythm is thinner than that of the Mugikawa coal measures, but
a coal seam is thicker and bears better and more constant quality than that of
the Mugikawa coal measures. Sediments of a rhythm form a lenticular body,
and 4 members of a rhythm make a unit of sedimentation. Sometimes flow-
structures and walls of rivers are found in the conglomeratic parts. Therefore
it is at least evident that the sedimentary body or a unit of the rhythm is pro-
duced by the shooting of the river (Flußschotter). It is interesting that the
constituents of pebbles are different with regard to the rhythms. For instance,
the fourth rhythm of the coal measures has no pebble of porphyrite, while
porphyrite pebbles are very common in the third and fifth rhythms. This
reveals that either the provenance varied frequently in the stage, or the river
frequently changed in its catchment areas.

Similar phenomena are reported from the Nagelfluh of the Alpine Molasse.
BÜCHI (1950) reported the alternating shooting activities of the two rivers, Ur-
Rhein and Ur-Ill in the Rheintal region of Swiss. BLISSENBACH (1957) reported
a change in provenance in the Nagelfluh of Bavaria region. Those alternat-
ing activities are considered as the result of change in elevating areas. In the

A   B
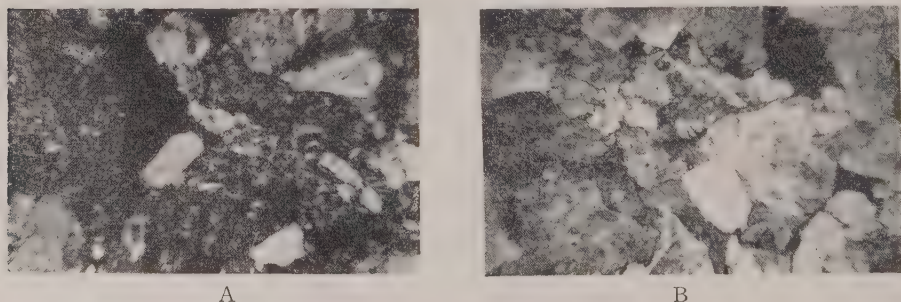
Figure 6. The Momonoki sandstone
Arenite of the Mugikawa coal measures (×20)
A: open, B: crossed nicol.
at a point 1.5 km E of Momonoki, Mine city.

Momonoki rhythm, the following mechanism of sedimentation is suggested. A unit of the rhythm is related to a stretch of fluviatile shooting, and the river changed its catchement area frequently, for which frequent change in the elevating area is responsible as in the Alpine Molasse.

Since each sedimentary body thins out both to the north and south, it is evident that the sediments were deposited in a lake. Arenites of a bed are almost uniform in coarseness, roundness and relative volume of sediments (maturity). This supports the Momonoki basin to have been completely closed or a lake. The distribution of sediments suggests (fig. 7) that the Momonoki lake was about 10 to 15 km in diameter in the Omine and Mugikawa stage. The lake was invaded in the last stage, and thick and black mudstones were deposited. The mudstone contains marine fossils, although it is very rare.

4.4. Condition of sedimentation

The Momonoki formation was on the whole deposited in a lake, i. e. the Momonoki lake. It was about 10-15 km in diameter in the Mugikawa and Omine stages, although it was somewhat wider in the stage of the Momonoki delta.

There are three type of sediments in the Momonoki formation; namely, composite and simple rhythms of Mugikawa and Omine types beside Momonoki delta. These three are similar to one another in the constituents of sediments, because they include coaly as well as muddy lacustrine sediments and conglomerates and coarse sandstones of fluviatile shooting. Through the three sediments conglomerates and sandstones are also similar to each other not only in the constituents, but also in their relative volumes, although the three sediments are distinguishable from each other in the coarseness and package of pebbles in conglomeratic parts.

Relative thickness of fine sediments to the whole thickness of a bed is much thinner in the deltaic deposit than in the two types of coal measures. Sediments are rhythmic in the two coal measures, but not rhythmic in the deltaic sediment. Coaly and muddy sedimedts are deposited in the middle part of the bottom-set beds and conglomerate of the lateral facies of a delta in the middle Momonoki stage. Therefore conglomerate of the deltaic as well as lateral facies and finer sediments must be products of one shooting phase. In the two coal measures the fine members, including coal and muddy sediments, lie on the conglomerates and sandstones. The two members are related to each other in the stratigraphic relations and form a unit of rhythm or a sedimentary body. They are also considered to be produced by the fluviatile shooting. Therefore all fine and coarse sediments are closely related to each other in three types of sediments, and they are shooting sediments by a river. Thus the three types of sediments are identical to one another in the constituents of sediments as well as genesis, except for minor differences in the arrangement of sediments.

Rhythmic and deltaic sediments like the Momonoki formation are also found in the Alpine Molasse. They are well represented by Rigi-rhythm and

Nagelfluh-conglomerate. These two sediments are closely related to each other also in the Alpine Molasse.

Then, what does the difference among the three types of sediments in the Momonoki formation mean?

If the three types of sediments are related to one another in the genesis of the fluviatile shooting, the difference among them may depend upon the difference in crustal movements, which control the mechanism of shooting.

Since a unit of sediments is related to a stretch of shooting, the volume of conglomerate and sandstones represents the energy of shooting. Volume ratio of coarse member to each unit of sediments is as follows (1958, d. p. 542):

Mugikawa coal measures: Momonoki delta: Omine c. m.=4:42:3.

(Here the volumes of Mugikawa and Omine coal measures
represent the mean value of a rhythm.)

This ratio is related to the intensity of shooting, and therefore to the intensity of crustal movements in the three stages of the Momonoki formation. In the shooting deposits coarseness and package of phenoclasts are also related to the power of shooting. If they are considered, the ratio of shooting intensity will be much larger in the Momonoki delta than in the two coal measures. The difference in the shooting intensity is responsible for the difference among three types of sediments in the Momonoki stage. The difference between the two types of rhythmic sediments can be also explained by the difference in the shooting intensity. The Omine rhythm is related to the minimum energy of upheaval, while the Mugikawa rhythm is related to the larger intensity than the Omine rhythm. The Momonoki delta is to do with the elevating energy much larger and probably more than ten times as large as the two types of rhythms. Since the elevating energy depends upon the amount and velocity of upheaval of a larger areas than the two rhythms. The Omine rhythms is probably related to the upheaval of the smallest areas among the three types. Therefore it depends probably upon the frequent upheavals of small areas. This is also supported by the features of sediments.

5. *Aso formation* (KATAYAMA, 1938; em. TOKUYAMA, 1958c, d, 1960a)

The Aso formation is composed on the whole by massive and monotonous sandstones, in which shales or alternations of marine and non-marine bands are inserted. They yield fossils suggesting various conditions of paralic basins. The Aso formation is divided into four units. The general succession is in ascending order as follows:

1.	Inoki coal measures, brackish	150 m thick
2.	Mitsusugi sandstone, neritic	800 m
3.	Oda coal measures, paralic	150 m
4.	Sonose sandstone, paralic or neritic	450 m

5.1. *Inoki coal measures* (TOKUYAMA, 1958c, d)

The Inoki coal measures lie with slight unconformity or diastem on the alternation of the top member of the Omine coal measures. They are com-

posed of massive sandstones, in which thin bands of coal and muddy sediments are inserted. They are therefore made up of two members, fine grained and coarse grained members as in the rhythmic sediments of the Momonoki formation. They resemble the Omine coal measures superficially and in fact HASE (1951) referred them to the Momonoki formation, but they are distinguishable from the Momonoki coal measures by the following characteristics.

Coal, mudstone and coarse grained conglomeratic sandstone are combined to form a unit of rhythm in the Momonoki formation, but they represent different facies and form two independent units in the Inoki formation. The coarse member is made up of conglomerate and sandstones; their grain size decreases upward in the two coal measures of the Momonoki formation, but it is monotonous in the Inoki coal measures. The thickness-ratio between the fine and coarse members is larger than 1/8 in the Omine and Mugikawa coal measures, but smaller than 1/25 in the Inoki coal measures.

The fine member of the Inoki coal measures consists of coal, coaly shale and alternation of mudstone and shale. Sometimes mudstones are fairly thick, but in some cases they are absent, and coal seams lie on the massive sandstone directly. A coal seam is, though thin, widely distributed and almost uniform in thickness through the Inoki basin. Its quality is good in the northern part, but becomes worse to the south. Finally, it is replaced by coaly shale. In the two coal measures of the Momonoki formation, a coal seam is thickest and of best quality, where a rhythmic bed is thickest and coarsest, but it is thin-bedded and bearing bad quality at the both margins of the basin.

Sandstones of the Momonoki formation are almost uniform in coarseness and constituents through the basin. In the Inoki formation they are somewhat different between the northern and southern parts of the basin in the roundness and relative volume of constituent minerals. They are better rounded and sorted in the southern than in the northern part. In other words the maturity is more advanced in the south than the north. Therefore it is evident that the Inoki basin was not closed, but open southward.

An *intercalation* of carbonaceous sediments in the lower part of the Inoki coal measures is 1.75 m thick and has the following succession:

Massive sandstone (upper member)

6. 20 cm thick : Alternation of mudstone and shale in which mudstone merging upward into clay, finely banded.
5. 25 cm   : Coal seam with two thin intercalation of clay; 5 cm (low.) and 3 cm (up.)
4. 30 cm   : Pure massive coal
3. 25 cm   : Frequent alternation of clay and coal (clay>coal)
2. 30 cm   : Clay with 3 thin insertions of coaly layers; 3 cm, 1 cm, 6 cm.
1. 45 cm   : Alternation of fine sandstone and mudstone

Massive and coarse sandstone (lower member)

The lower sandstone is coarse and massive, but in the uppermost part it merges into somewhat finer sandstone. The alternation of the first member

is characterized by the upward decrease in grain size. It is therefore similar to the "graded bedding" in the grain size-change, but it is not so regularly bedded as graded beds; the lower boundary of the fine sandstone is not so distinct as in the graded beds. The alternation reveals the oscillation rather than the "turbidity current".

Another insertions of coaly sediments of the Inoki coal measures have also similar lithologic characters as the band above exemplified, although the ratio of coal to mudstone is variable.

Because the Inoki formation is inserted between the limnic Omine coal measures and neritic Mitsusugi sandstone, it is evident that the massive sandstone and intercalations of carbonaceous sediments have been deposited during the subsidence of the basin, as in the case of the Takiguchi coal measures.

5.2. Mitsusugi sandstone

It begins with the thick shaly insertion attaining 30 m thick. It is similar to the subjacent beds in the massive sandstones, but the intercalations are here marine bands, instead of coaly sediments. Sandstones are better agitated in the Mitsusugi than the Inoki stage. Relatively good roundness, sorting and high maturity of the Mitsusugi sandstone suggest that they have been reworked repeatedly before they are settled, and that the basin was kept in a constant and stable condition.

These monotonous sandstones are barren of fossils, but Mitsusugi sandstone includes marine pelecypods in two facies. They are *Tosapecten* shale (1960a, facies A) and *Waagenoperna*-sandstone (1960a, facies B). The *Tosapecten*-shale is a shaly or muddy intercalation between the monotonous sandstones. It is about 30 m thick in the lowest bed but commonly 5 to 10 m thick. The interspace between the two *Tosapecten*-shales varies from 80 m to 190 m in thickness (1960a, text-fig. 1, p. 25). The shale always contains *Tosapecten suzukii okadai* and in rare cases *Homomya*, *Anodontophora* and *Chlamys*. It is noted that fossil localities are restricted in the middle part of the basin, except for a locality to the north of Momonoki, where the shale yields *Anodontophora*.

Properties of shaly intercalations

A shaly bed in the upper part of the sandstone consists of three members (1958d, p. 547, fig. 6-I). The lower member consists of alternation of black shale, somewhat muddy or bituminous; it is characterized by upward decrease in grain size as in the lower member of the Inoki-mudstone. The middle member is made up of two parts. Its lower part is frequent alternation of black shale and black sandy shale, characterized by continuous change in grain size; a shaly bed gradually merges up- and downward into sandy shales. The lower sandy shale which is somewhat massive, yields *Tosapecten*. The upper one is characterized by fine black shale with fine striation of light coloured layers. The upper member is composed of alternation of somewhat carbonaceous mudstone and black shale and characterized by upward increase

of grain size. The lower member is somewhat muddy or bituminous and includes mica flakes, while the upper part is somewhat carbonaceous. The middle member is well stratified and bears smallest grains among three members. These three members form a complete cycle and represent transgressive, inundation and regressive facies. Gentle warping of the basin was responsible for these three facies. Other shaly insertions also consist of the three facies, although some beds lack a transgressive member or a regressive member. The intercalation, comprising the three facies, represents a typical cycle from gradual subsidence to emergence of the basin. But when the subsidence is rapid, the intercalation lacks the transgressive facies and begins with the inundation facies; when the emergence of the basin is rapid, or when there is a sudden shooting of sandstone, the intercalation lacks the regressive facies.

The second fossiliferous facies is the *Waagenoperna* sandstone which contains *Cardinia* and *Plagiostoma* in the southern part of the basin, *Chlamys*, *Tosapecten* and *Waagenoperna* in the middle and *Waagenoperna* and *Limatula* in the northern part. They form fossil banks. The sandstone is very coarse and poorly sorted. The *Waagenoperna* facies suggests less circulating water than the surrounding monotonous sandstone.

Properties of sandstones

Because there are several key beds of shaly intercalations in this sandstone, it is fairly easy to pursue a sandstone horizon through wide areas. A sandstone varies from place to place horizontally, not only in roundness and sorting, but also in constituent. The Mitsusugi sandstone includes two types of rocks, A and B. They are different from each other in roundness, sorting and constituents of grains as well as matrix. The A type is more common than the B type and represents massive sandstones, while the type B is inserted as relatively thin bands as *Waagenoperna* sandstone.

A-sandstone (Pl. XVII, fig. 1-4)

In the northern part of the basin sandstones are composed of rock fragments of andesites (30-44%), schists (2-4%), and sedimentary rocks (5-20%), such as sandstones, cherts and shales, besides fragments of granitic rocks (40-50%), in which mica, microcline, orthoclase and albite are enumerated. They are similar to the Momonoki (fig. 6) sandstone in composition and texture, and no effect of water current is recognized (Pl. III, fig. 1). The two dominant constituents of the Mitsusugi sandstone are fragments of andesites (inclusive of trachytic andesites) and granitic rocks. The former attains sometimes 45% and the latter is about 40% in Shimizuda and Ishiyakata district, 3 km to the north of Aso. Towards the south andesitic fragments are abraded to disappear (Pl. XVII, fig. 3). Near the middle of the basin, at Imayama, about 2 km to the south of Aso, relative volume of andesite is about 20-50%. Andesites almost disappear near Hoho (Pl. XVII, fig. 4), 5 km to the SSW of Aso. There microcline is rounded, but its diameter is as large as in the northern part. To the south of Hoho, microcline tends to be abraded. Then albite and

orthoclase are crushed. Thus the quartz/feldspar-ratio becomes larger in the south. At Michiichi, 10 km to the south of Aso, quartz and feldspar occupy 75% of the total volume and quartz/feldspar-ratio is 1.2 or so, but it is 0.9–0.7 at Ishiyakata in the northern part.

These sandstones are characterized by relatively scarce matrix, well sorted and abraded grains and original voids, although the voids are filled with secondary precipitates (Pl. XVII, figs. 1, 2). The change in the relative volume of constituents represents the *maturity*. Commonly the maturity is represented by quartz/feldspar-ratio or the ratio of quartz & chert/feldspar & matrix. This is based upon the fact that quartz is stable and hard to be destroyed and altered, while feldspar is unstable or relatively easy to be destroyed or decomposed. Therefore quartz-feldspar ratio indicates the effect of water-current in the basin. Unstable matters are destroyed and disappear by current of water during transportation. Sandstones of the Mine series, however, include so many unstable fragments, that feldspars belong to stable members rather than unstable fragments, because andesites are more unstable than feldspars. There the rate of crushing of andesite fragments indicates the rate of current efficiency during the transportation of sandstones. It is however, rather hard to measure the volume of andesites exactly, because matrix includes andesite fragments, and sometimes it is hard to distinguish the andesite fragments from matrix.

The B-sandstone (Pl. XVII, figs. 5–8)

In the sequence of marine sandstone are inserted layers of another sandstone, in which texture and constituents are somewhat different from the A-sandstone. Constituents of the B-sandstone are more angular and ill-sorted than the A. They are filled with matrix of detritic andesites. In the northern part of the basin they are similar to the A in constituents and texture, becaues effect of water current is weak. Toward the south B-sandstone is distinguishable from the A in texture and constituents or by the mode of abrasion and fracturing in grains. There andesites and microcline are destroyed almost simultaniously, although the former is more easy to be fractured than the latter. Near Aso andesites are crushed into small fragments; microcline begins to be fractured; sands are cemented with matrix which is originated in the andesite fragments. Further to the south at Imayama, large part of andesites is crushed into matrix, and microcline-crystals are also fractured into small fragments. In the A-sandstone, microcline crystals are rounded but not fractured at Imayama; in the B-sandstone they are angular but small. The A-sandstone is provided with poor matrix, but the B-sandstone is filled with matrix of andesite fragments. The difference between the two types of fracturing probably depends upon the nature of current, because there is no difference between the two sandstones, where water current was weak. The water current was weak or moderate in the A-sandstone. Constituents were rolled and repeatedly reworked in the basin during transportation, where such unstable fragments as andesites and schists are fractured

into small fragments. Incidentally microcline crystals are rounded. In thin layers of the B-sandstone, effect of current is shown by fracturing of sediments, although some fragments are abraded. They are fractured in the transportation, but rarely reworked after deposition, so that small andesite fragments remain as matrix, instead of being washed out.

Toward the south, the difference between the two types of sandstone becomes distinct. They are distinguishable from each other even megascopically. Rounding and sorting are more advanced in the A-sandstone than the B. The A-sandstone is clearer, purer and more quartz-rich than the B, which the latter is filled with clastic matrix of andesite, dirty green in colour.

In the Mitsusugi sandstone the A-sandstone is more common than the B. The former is a kind of arenite (GILBERT, 1954) and belongs to the clean sandstone series; its final products are represented by "orthoquartzites". They are so-to-speak an immature equivalent of orthoquartzite. The B-sandstone is rather rare in the Mitsusugi sandstone and represented by thin intercalations of *Waagenoperna* sandstone. It is distinguished from the A-sandstone by more angular and illsorted fragments besides its clastic matrix which is absent in the A. In the PETTIJOHN's classification, this sandstone may belong to "graywacke", because it bears matrices, many unstable constituents and relatively angular rock fragments. But it is distinct from graywacke not only in texture, but also in constituents, because grains are rounded, sorted and stratified to some extent in this sandstone. The most fundamental difference between graywacke and this sandstone lies in matrix. It is muddy and autochthonous to the basin or original in graywacke, but it is occupied by fragments of andesites, which were transported together with other fragments in the B or *Waagenoperna*-sandstone. This sandstone forms thin intercalations in the A-sandstone and often merges into the A-type. Therefore the two sandstones in the Mitsusugi sandstone are closely related to each other essentially, and should be distinguished from graywackes.

The monotonous sequence of the Mitsusugi sandstone indicates that the basin was kept in the constant condition in the Mitsusugi stage. The change in maturity of sandstone suggests that the basin was open southward, where water current was strong. Because sandstones were often reworked, it is evident that the basin has been stable. Toward the last stage, the basin became shallow and *Waagenoperna* sandstone was deposited. Then it passed into cyclic sediments of the Oda coal measures, which reveal oscillation.

5.3. *Oda coal measures* (TOKUYAMA, 1958c, d)

The Oda coal measures are composed of 3 coal seams and 2 marine bands among them. They make two complete and symmetric cycles, which are made up of transgressive and regressive hemi-cycles and inundation stage between them. The first cycle of the Oda coal measures is 90 m thick, and the second about 50 m thick. Members of the regressive hemicycle are arranged in the reverse succession perfectly matching with the transgressive hemicycles. They are composed of 3 shelly facies, beside coal seams, and

their distinctions lie in the fossil assemblage (1960a, p. 26). The first trans-
gressive hemicycle begins with a coal seam, which passes into *Anodontophora*
shale, then into *Tosapecten* shale and sandstone, through sandstone layers and
terminates with *Eumorphotis* sandstone. The last represents the most off-
shore facies and therefore the inundation stage. In the regressive hemicycle
Eumorphotis sandstone is succeeded by *Tosapecten*-bearing sandstone, then by
the *Anodontophora* shale, and terminate with a coal seam. In the second cycle
the inundation facies is represented by *Rhynchonella* shale instead of *Eumor-
photis* sandstone. The shell assemblage of the three facies suggests the
oscillation of the strand line or undulation of the basin.

　　An interesting fact in this coal measure is the alternation of the "reverse
grading", which begins with shale and merges upwards into mudstone. It is
characterized by upward increase of grain size (1958, p. 545, fig. 6–IV). Some-
times ripple markes are found on the surface of the mudstone. Because this
alternation includes coal in the upper part, and lies on marine bands, the
alternation and ripple marks indicate the regression or upheaval of the basin.
In the grain-size change it is reverse to the alternation found in the Inoki
coal measures, which were deposited at the time of transgression. The ripple
marks suggest the littoral zone. They are important indicators of the pala-
eogeography. The coal seam of this horizon can be pursued as far as Ima-
yama, where the coal seam is replaced by coaly shale and then by mudstone
further in the south. Thus coaly matters were distributed in the Aso bay for
7–8 km from the littoral zone to the south.

5.4. *Sonose sandstone* (KATAYAMA, 1938; TOKUYAMA, 1958c, d)

　　It begins with thick *Waagenoperna* sandstone (70 m thick). It is followed
by massive sandstones of Mitsusugi type, about 350 m thick in which 3 layers
of *Rhynchonella* shale, 2 of *Waagenoperna* sandstones, 1 of *Tosapecten* shale and 2
Anodontophora shale and a coaly layer are intercalated. All of these intercala-
tions are similar to those found in the three subjacent stages. They are
neither cyclic nor regularly arranged as in the Oda and Mitsusugi stages.
Therefore little is added here to the lithologic and biologic facies.

5.5. *Sedimentary condition of the Aso formation*

　　The Aso stage is represented on the whole by monotonous sandstone of
the Mitsusugi type, in which either marine and brackish shelly facies or
carbonaceous facies are occasionally intercalated. Otherwise, the basin was
in the constant condition. The marine bands suggest the transgressive or
subsiding stage, while the coal seam reveals the regressive stage. The sym-
metric cycles of the Oda coal measures suggest gradual deepening and shal-
lowing of the basin. It is similar to the faunal cycles in the Carboniferous
of the Ruhr region in the subvariscan basin, which is composed of three
shelly facies, namely non-marine shell bed, *Lingula* bed and *Goniatite* bed
(JESSEN, KREMP and MICHELAU, 1952). Coaly alternations of the Oda stage
represent the regressive phase, while those of the Inoki show the transgressive

phase. Fine grained intercalations in the Mitsusugi sandstone carry all of the transgressive, inundation and regressive facies, and the three make a complete cycle of sedimentation.

II. Tectonic Control of Sediments

1. Three types of sediments in the Mine series

Most sediments owe their existence to crustal movements. If there is no upland, no detrital sediments would be produced. On the other hand, if basins did not subside, they would soon be filled up. These crustal movements are recorded in the aspect of successive strata. Thus the three different sediments of the Mine series, namely the Hirabara, Momonoki and Aso sediments suggest three different types of tectonic movement in the Mine epoch.

1.1. Difference between the Hirabara and Momonoki formations

The Hirabara and Momonoki formations contain psephites and rhythms, in which grain size decreases upward, but these features are quite different between the Hirabara and Momonoki formations.

The Hirabara type psephite is a kind of breccia, containing angular fragments of cherts and shales. Its matrix is composed of lithic wacke. On the other hand the Momonoki type is a conglomerate containing round pebbles of andesites, granitic rocks, gneissose rocks and schists, beside chert, sandstone and shale. Its matrix is lithic arenite, similar to conglomerates in constituents.

The difference between the two types of psephites lies in the following points:

Phenoclast is angular or little rounded in the Hirabara type, but well round in the Momonoki. The former is less sorted than the latter. The phenoclasts of the Hirabara conglomerate are composed of Palaeozoic rocks of the Yamaguchi group, and therefore monogenetic, while pebbles are polygenetic in the conglomerates of the Momonoki formation, which received pebbles from the Hida and Sangun terrains as well as the Yamaguchi group.

Matrix of the Hirabara conglomerate is mudstone, which is original or autochthonous to the basin, while phenoclasts were supplied from the Yamaguchi group in the surrounding regions of the basin. The matrix is therefore of different origin from phenoclasts in the Hirabara type. In the Momonoki conglomerates, matrix is produced by fluvial shooting together with the phenoclasts; it is so-to-speak a kind of microconglomerate or arenite.

Mode of occurrence: In the Hirabara formation psephites are seen in the basal parts of the sedimentary cycles. They are coarse where strata are thick (1960b). Layers of psephites or breccias wedge into mudstone, which is autochthonous to the basin. In these areas are often found some irregular sedimentary features suggesting bottom slumping or currents of turbid water. In this sense they are similar to "Geröllton" or pebbly mudstones and "slideconglomerates" of KUENEN & CAROZZI's sense (1952). These psephites

PARALIC ASO
FORMATION

As-Hi

Sonose
Sandstone

SCHEMATIC PROFILE
OF THE MINE SERIES

Oda
Coal measures

300
200
100

1000 2000 3000

Mitsusugi
Sandsone

Inoki
Coal measures

LIMNIC MOMONOKI
FORMATION

Omine
Coal measures

Momonoki
Delta

Mugikawa
Coal measures

NERITIC HIRABARA
FORMATION

Third cycle

Coal seam

Minor rhythm (with coal)

Second cycle

Sandy shale

Alternation of sandst. & mudst.

First cycle

Coarse sandstone

Fore-set bed
Marginal facies of Momonoki delta

Basal conglomerate

BRACKISH TAKIGUCHI
FORMATION

Intercalation of marine shale
fine s.s.

Neritic sandstone

Figure 7. Schematic profile of the Mine series.
As-Hi : Standard section along the high way between Aso and Omine.

are explained to have been produced by slumping of the steep bottom, for which sudden subsidence of the basin was responsible (1960b).

In the Momonoki conglomerate cross laminations representing the fore-set beds of delta, muddy boulders reworked from the top-set beds, centre of

shooting and lateral facies of the delta or alluvial fan are found. All of them reveal fluviatile sediments or Flußschotter. Rounded and polygenetic pebbles and arenitic matrix or paucity of cementing materials correspond to the mechanism of fluviatile shooting. Because there is no particular deposits suggesting agitation or currents of water in the Momonoki delta, detritus seems to have been little removed in the basin before it is finally settled. Therefore the coarse Momonoki conglomerate depends upon the abrupt shooting by streams which was probably brought forth by the upheaval of the hinterland, rather than subsidence of the basin. Similar alluvial deposits as the Mine series are seen in the Idenoue delta of Asa area and Mogamiyama conglomerate of Nariwa area. In the Alpine Molasse shooting sediments of this type are well represented by many alluvial fans i.e. Schüttungsfächer of the "Nagelfluh", in which frequent changes in the orography of the hinterland are recorded (BÜCHI, 1950; BLISSENBACH, 1957). They are explained to have been related to the contemporaneous upthrusting (BODEN, 1926, CADISH, 1928).

Thus the two types of psephites are explained by the sudden subsidence of the basin (Hirabara) and rapid upheaval of the hinterland (Momonoki). In other words subsiding movements of the basin overcame the upheavals of the Hinterland in the Hirabara stage, while in the Momonoki stage the latter overcame the former. In the Momonoki stage the basin was relatively stable, but the hinterland, which was the axis of the Akiyoshiiden, strongly folded to make steep relieves. These two sediments represent two kinds of crustal movements. The other characteristic features of the Hirabara formation such as the three major cycles of sedimentation and small rhythms of graded beds, are also best explained by the strong subsidence in the basin. On the other hand the coal measure rhythm of the Momonoki formation supports strong and sudden upheaval of the hinterland (1958c, d).

1.2. Aso formation

The Aso formation is characterized by coarse and massive lithic arenites, occasionally intercalated by coal, *Tosapecten* shale and alternation of complete cycles (1960a). It is a general tendency of the Aso formation that sandstones are immature in the northern (near-shore) part, but more mature in the southern (off-shore) part. In the Aso basin sand grains were removed or reworked by currents repeatedly before they are settled. This suggests that the basin was relatively stable in this stage and shootings of sediments were not so strong as in the Momonoki stage. Such monotonous or massive sediments as in the Mitsusugi sandstone is explained by the equilibrium between the shooting of sediments and subsidence of basin. Voluminous coarse sediments were derived from elevating areas, because the basin was stable in this stage as in the Momonoki stage. Hinterlands were probably wider, but their geographic relieves more gentle than in the Momonoki stage. Sediments are coarse and massive in this stage and there is no particular sediments suggesting either strong fluviatile action as in the Momonoki delta, or currents of turbid

water as in the Hirabara stage. The complete faunal cycle of the Oda coal measures or the middle Aso formation, suggests gradual transgression and regression, related to the warping of the basin.

In the Mitsusugi sandstone the *Tosapecten*-shale represents a deeper facies than the surrounding sandstones. It was deposited when more or less strong subsidence has taken place in the basin, and the sea became deeper because the *Tosapecten* shale is composed of transgressive, inundation and regressive facies. The tectonic control of the elevating hinterland exceeds that of the subsidence of the basin in other stages of the Aso formation, because the Aso sandstone belongs to the Momonoki type, although shootings of sediments were not so strong in the Aso as in the Momonoki.

If the sediments of the Aso stage represent a more gentle crustal movement of the Momonoki type, there will be another sediment representing the more gentle movement of the Hirabara type. The Nakatsuka formation in Asa area is an example which is characterized by massive graywackes or banded graywackes, inserted by marine shales of *Halobia* and *Asoella*-facies. It belongs to the Hirabara type sediment (p. 47ff).

Finally the three types of sediments in the Mine series are explained from the tectonic standpoint as follows:

1) The Hirabara formation represents an intense subsidence of the basin which was extremely unstable in the Hirabara age.

2) The Momonoki formation represents intense and repeated upheavals of the hinterland, while the basin maintained a relatively stable condition.

3) The Aso stage represents a gentle upheaval of the hinterland. Topographic relieves were more gentle and wider in this stage than the Momonoki stage. The basin undulated gently.

2. *Three types of rhythmic sediments*

Each of the three formations comprises characteristic rhythmic sediments, which are here explained by the tectonic control.

2.1. *Hirabara rhythm* (1958d, 1960b)

2.1.1. Major cycles

The Hirabara formation includes three major cycles of sedimentation. Each cycle of sediments is about 400 m thick. It is made up of alternation of breccia and coarse lithic wacke in the lower member, alternation of graywackes and shales with bituminous sandstones in the middle member and a coal seam or carbonaceous matter-bearing alternation of mudstone and sandstones in the upper (1958d, 1960b). As suggested by the thickness and facies-change (fig. 7), the cycle is explained by great supply of sediments followed by the abrupt subsidence of the basin. When subsidence was active, the basin received breccias from surrounding areas. The psephites are best developed where the total thickness of strata attains the maximum. To the south of the subsiding area they pass into graywackes and subgraywackes, and to the north they are replaced by black mud-bearing sandstones. The

breccia is sometimes a wedge in bituminous sediments and cemented by black mudstones. Reworked pebbles and "convolute beds" suggest bottom sliding on the slope between the northern shallow and stable part and southern deep and unstable part. In the middle member of the cycle, where graded beds predominate, the crustal movement became less intense than before, but the subsidence of the basin was still active. The lower member is controlled by excess of subsidence over the sedimentation, because many sediments indicate bottom slumping. When the rate of sedimentation attained almost equal to the rate of subsidence the sediments may be monotonous. The monotonous or uniform graded beds may indicate such a sedimentary condition.

The uniform graded beds suggest "turbidity currents", which take place constantly, while the "sliding conglomerate" or the like of the lower member suggests an abrupt "bottom slumping". The so-called "turbidity current" is distinguished from the "bottom sliding" by mechanism (KUENEN, 1960). The difference between the sliding conglomerate of the lower member and graded beds of the middle of the Hirabara formation, can be explained by the different mechanism between the "bottom sliding" and "turbidity current". The former is related to the larger "shooting intensity" than the latter.

The graded beds of the Hirabara formation are followed by bituminous sediments, which suggest stagnant condition of an embayment and contain pelecypods of shallow and stagnant water. Sediments tend to become finer and shales and mudstone exceed psephites and psammites in the upper member. Here several coal seams as well as carbonaceous pellites are inserted. It is evident that the basin was filled up in the upper stage of the cycle. It suggests that the subsidence was so receded that the basin was filled up with sediments.

After the deposition of paralic shales and sandstone, an abrupt subsidence has taken place once more in the basin and coarse breccias were deposited on fine sediments. The grain size again decreases upwards. This is explained by the renewal of filling, followed by the sudden subsidence.

2.1.2 Graded bedding

Beside three major cycles of sediments there are many small rhythms of sedimentation called "graded bedding". They are found chiefly in the middle and lower members of the major cycle.

A simple rhythm of the graded bedding is composed of graywackes in the lower part which decrease upward in grain size and pass in mudstones in the upper part. The mode of grading is different between the northern (near-shore) and southern (off-shore) sediments. The grain size changes gradually in the northern part, where sandstone contains more muddy matrices than in the south. The change becomes more sharp and muddy matrix of sandstone is less in the south, so that the sandstone becomes more pure and sorted. Fine grained constituents of the rhythm become also well sorted in the southern part. Therefore the change in grain size from sandstone to shale becomes more rapid in the south than in the north.

2.2.   *Two types of rhythm in the Momonoki formation*

The Momonoki formation contains two coal measures and a deltaic sediment between them.   The lower or Mugikawa coal measures include three large cycles; each composed of conglomeratic sandstone in the lower member and coal seam-bearing alternations in the upper.   The latter comprises many small and incomplete rhythms composed of fine sandstone, alternation of mudstone and carbonaceous shale and coal seam or clay.   Therefore the Mugikawa rhythm is a composite cycle, where coal seams appear frequently, and their thickness and quality change also frequently.

Another rhythm, represented by Omine coal measures, is more simple than the preceding and composed of coarse or sometimes pebbly sandstone in the lower, alternation of sandstone and mudstone in the middle and black coaly shale and coal seams in the upper member (Pl. XV, figs. 5, 6).   One rhythm in the Mugikawa coal measures is about 100 m, but 10–20 m thick in the Omine.

In comparison with the psephite of the Hirabara and two Momonoki rhythms, the Hirabara rhythm includes lithic- and graywackes, but psephite of the two Momonoki rhythms belongs to the arenite group or the fluvial conglomerate from the rising hinterland.   The provenance of the sediments in the two Momonoki rhythms was situated in the axial zone of the Akiyoshi folded mountains, while the Hirabara basin received sediments from the surrounding areas, where non-metamorphosed Yamaguchi group was distributed.

The Momonoki rhythm is explained from the tectonic standpoint as follows:

Voluminous coarse arenites containing pebbles in the lower member were derived from maturely dissected land, which had been produced by strong upheval of the Momonoki orogenic phase (Kobayashi, 1941).   The shooting was continued while the land relief was steep.   They became finer in accordance with the leveling by erosion.   In these stages, sedimentation was rapid, and weathering weak, as understood from fresh rock fragments of the Momonoki sediments.   When the basin was filled up and land relief became moderate, the sediments merged into plant-bearing mudstones.   Finally, a considerable amount of coaly matter was deposited.   When the relief of hinterland became steep, coarse sediments were again transported into the basin.   No effect of agitation is found in the Momonoki formation.   Therefore the basin may have been more stable at the time than in the Hirabara stage.   Thus the difference between the Hirabara and Momonoki rhythms is explained in the same way as that between the two kinds of psephites.

In Asa area the Mugikawa composite rhythm is represented by the Tsubuta coal measures and the Akaiwa alternation, and the Omine type is represented by simple rhythms of the Yamanoi formation, which was deposited in a wider basin than the Momonoki lake.   The equivalent of the Momonoki delta in Asa area is represented by the Idenoue delta.   In Nariwa area similar rhythmic sediments are described as Hinabata (Omine type) and Mogamiyama (Mugikawa type) rhythms (Tokuyama, 1960d).

The difference between the Mugikawa and Omine rhythms lies in the thickness of coarse sediments, beside sedimentary features of the ryhthms in

fine grained sediments. The Mugikawa rhythm includes coarser and more voluminous arenite than the Omine rhythm. The volume ratio of the coarse grained member of one rhtymic unit is in mean value as follows:

$$\text{Mugikawa rhythm}:\text{Omine rhythm}=4:3$$

The Mugikawa coal measures contain coarser grains than the Omine ones. Therefore it is evident that the shooting intensity is higher in the Mugikawa than in the Omine stage. It is suggested that the Mugikawa rhythm is related to a stronger fluviatile transportation than the Omine.

In the Saar-Saale region the Dinantian coal measures are described as a sequence of the rhythmic sediments (TRUEMANN, 1945) showing similar composition as the Momonoki rhythm. It has been suggested that the Asturic phase of orogeny was responsible for the major folding of the Westphalian rocks in the sub-Variscan fore-deep. In the Saar basin Upper Carboniferous rocks, 15,000 feet in total thickness, were accumulated. They include many conglomerate layers with pebbles derived from the Hercynian granites and other rocks of the Variscan mountains. They include also clay of exceptionally fine grains, indicating calm water. There are numerous coal seams on "seat earth".

In the Alpine Molasse the Momonoki type of rhythm is well represented by the "Rigi-type" rhythm in the fresh-water Molasse. The rhythmic sediment is often provided with Nagelfluh or conglomerates of alluvial fan. Therefore the rhythm may be explained by the similar genesis as the Nagelfluh.

In conclusion these rhythmic sediments are common in the "metaorogenic deposites" and record the elevation of the hinterland. They are sometimes coal-bearing as in the Momonoki, Kajiura and Saar, but sometimes coal is absent as in the Yamanoi, Mogamiyama and in the Alpine Molasse. Whether they are coaly or not may be related not only to the orography and vegitation of the hinterland, but also to the condition of the sedimentary basin or the chemical properties of water.

2.3. Aso rhythm

2.3.1. Major cycles

The Aso formation is characterized by massive and monotonous coarse arenite, in which thin beds of shales or mudstone are occasionally intercalated. The Oda coal measures or the middle Aso formation is composed of two complete or symmetric cycles. They are explained by undulation of the basin, because biofacies changes are successive from brackish to neritic through embayment facies. A rhythm includes transgressive, inundation and regressive facies. The transgressive hemicycle includes coal seam, brackish *Anodontophora* shale, *Tosapecten* shale or sandstone and *Asoella* sandstone in ascending order. The inundation phase is represented by *Asoella* sandstone in the lower and by the *Rhynchonella* shale in the upper cycle. It includes an open-sea fauna, and the rocks of the inundation facies suggest the basin to be open

southward. The regressive hemicycle is just reverse to the transgressive one in succession. The successive change of the Oda coal measures is similar to that of the faunal cycle in the Ruhr-Karbon, which includes brackish pele-cypod facies—*Lingula* shale—*Goniatite* shale—*Lingula* shale—brackish pelecypod facies. It is also compared with the Carboniferous coal measure cycles of Eng-land, which is marked by transgressive "marine bands". Pennsylvanian cycles in the United States include also similar changes in biofacies, although they are represented by algal and fusulinid limestones instead of molluscan and brachiopod shales. For these rhythms the ferm "complete cycle or symmetric cycle" is applied and they evidence oscillation of sea level.

    2.3.2. Small rhythms

    The oscillatory movements are recognizable by the change not only in biofacies, but also in lithology, or more precisely, by the features of alternat-ing beds including sandstone, mudstone and shale.

    In the transgressive phase an alternation has similar aspects as graded bedding and it is characterized by upward decrease in grain size; in a unit of rhythm sand passes upward into mudstone. The rhythm is, however, not so uniform or regular as in the graded bed, because oscillatory movements were not so regular as constant "turbidity currents". The graded bed repre-sents the regularly arising "turbidity current".

    "Reverse grading" is often found in the alternation of the regressive stage. In this alternation, grain size increases upward and mudstone merge into muddy sandstone in a bed, which is bounded by fine mudstone of the next bed. The upper boundary of the rhythm is often marked by ripple marks (1958d, p. 557).

    In the Inoki coal measures a coal seam is associated with alternations of the transgressive stage, while it is inserted in the regressive facies in the Oda coal measures, because coal seams follow the alternation of the "reverse grading" (1957d, fig. 6-IV).

    A *Tosapecten* shale in the Mitsusugi sandstone carries all the three types of alternations, namely the lower transgressive facies, middle inundation and the upper regressive facies (1958d, fig. 6-I). These three facies are distin-guishable not only by the successive change in grain size, but also by petro-graphic properties. The transgressive facies carries somewhat bituminous shale and sandstones, containing mica flakes and cemented with muddy matrix. The inundation facies is characterized by purer shale and sandstone or better sorted sediments than the transgressive facies. Grain size changes not appa-rently, and sandy shale passes gradually into shales both up- and downwards. The regressive facies is often characterized by carbonaceous mudstone. A similar lithologic succession is also observed in the rhythmic deposits of the Cretaceous Ofunato series in Matsusaki area.

3. *Crustal movements and sediments*

    In conclusion textures of sediments, mode of occurrence and aspects of rhythmic sediments are largely controlled by contemporaneous crustal move-

ments of the sedimentary basin and its hinterlands. One can distinguish two
principal types of crustal movements in the sediments of the Mine series.
They are 1) up-heaval the hinterland and 2) subsidence of the basin. The for-
mer is represented by sediments of the Momonoki delta, two types of coal
measure rhythms of the Momonoki formation and coarse and massive arenite
of the Aso formation. The latter is represented by slumping sediment as well
as by a major and minor rhythm of the Hirabara formation. The two types
of crustal movements are also evidenced by the constituents of sediments.
The Hirabara basin received sediments from the surrounding Yamaguchi
group. In the Momonoki and Aso stage sediments were derived from the
axial zone of the Akiyoshi folded mountains beyond the Yamaguchi terrain.
Psephites and psammites belong to a kind of wacke* in the Hirabara forma-
tion. They are composed of angular fragments of Palaeozoic rocks and filled
with muddy and bituminous sediments. Convolute beds and sliding conglom-
erate indicate that the Hirabara basin was unstable. Conglomerates and sand-
stones of the Momonoki and Aso stages belong to the arenite series.* They
were transported by streams into the relatively stable basin. The basin was
a lake in the Momonoki stage and an embayment in the Aso stage. The Aso
sediments were reworked and washed by currents in the basin, seeing that
they are rounded and well sorted.

III. Mine series in Asa area, Nagato

1. General geology

The Mine series in Asa area is 3000–6000 m thick and distributed between
the Habu-Tsubuta coast in the west and Funaki in the east. It covers weakly
metamorphosed Palaeozoic rocks at Go, 6 km to the south of Asa (fig. 3b).

The series begins with the basal Takago conglomerate, containing angular
fragments of Palaeozoic rocks. It is succeeded by non-marine sediments of the
Kajiura formation, composed of lower Akaiwa coal measures and upper Idenoue
delta. They are followed by marine sediments of the Nakatsuka formation,
which includes *Halobia*-shale in the lower part and *Asoella-Halobia* shale in
the upper. The fourth is the Yamanoi formation, made up of numerous and
regular rhythmic beds of sandstone and alternation, containing plant fossils
of the famous 'Yamanoi plant bed'. The last is marked by neritic Kamosho
formation, containing neritic *Monotis*-beds, which are replaced by non-marine
beds in the west at Hikiji.

The Nakatsuka and Kamosho formations are marine and fossiliferous, yield-
ing pterioids, which are important for correlation. The *Halobia*- and *Asoella*-
beds of the Nakatsuka formation suggest the formation to be younger than the
Hirabara formation in Mine area, as does the *Monotis*-shale of the Kamosho
formation to be younger than the Aso formation in Mine area. Rhythmic and
fluvial sediments of the Kajiura and Yamanoi formations have similar charac-

* In this paper I use the terms of *wacke* and *arenite* after GILBERT'S scheme of
classification (1954).

Figure 8. Geologic map of Asa area.
a: gravel bed, b: Tertiary, c: dyke rocks, d: Inkstone, e-i: Mine series, e_2: Ka-
mosho formation, e_1: Hikiji bed (brackish), f: Yamanoi formation, f_1: rhythmic
beds of ss. & alt., f_2: rhythmic alternation of 2 kinds of sandstones, g_1: Nakatsuka
formation, g_2: fossil beds, h: Kajiura formation (coal measures and deltaic conglom-
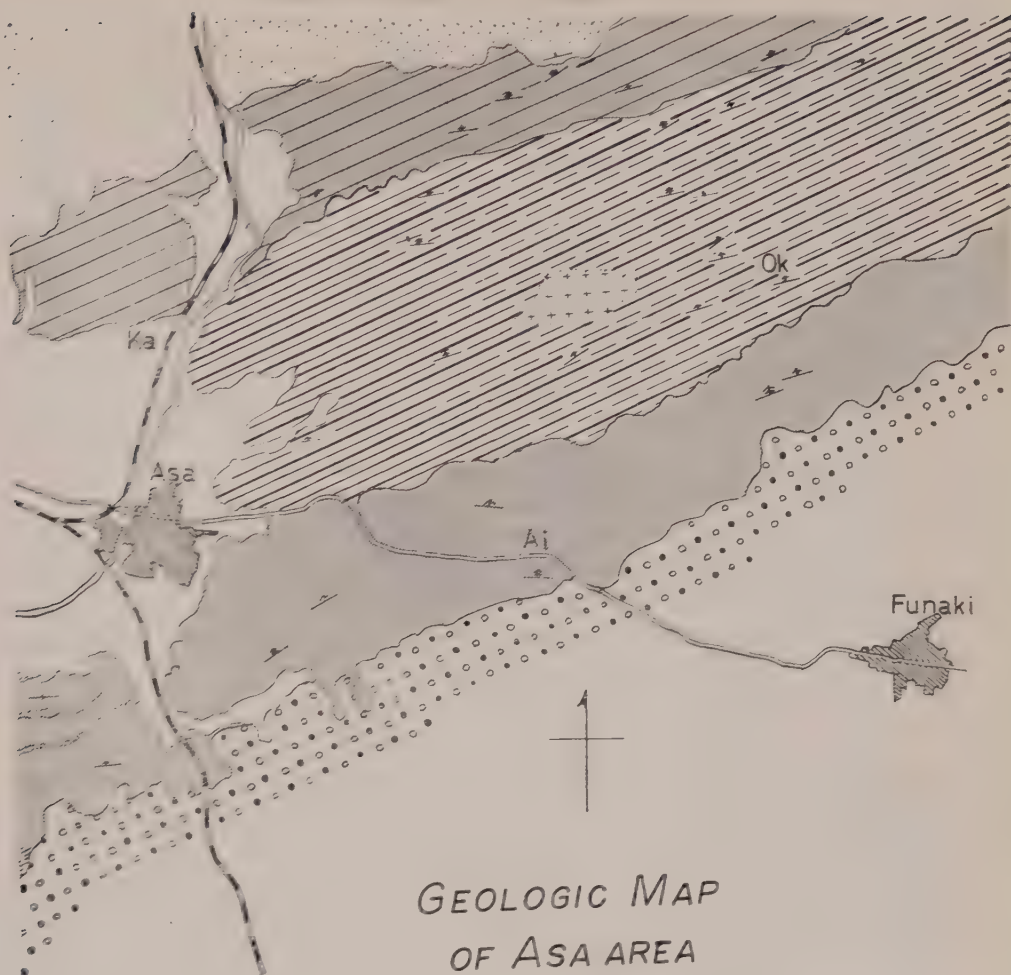
GEOLOGIC MAP
OF ASA AREA
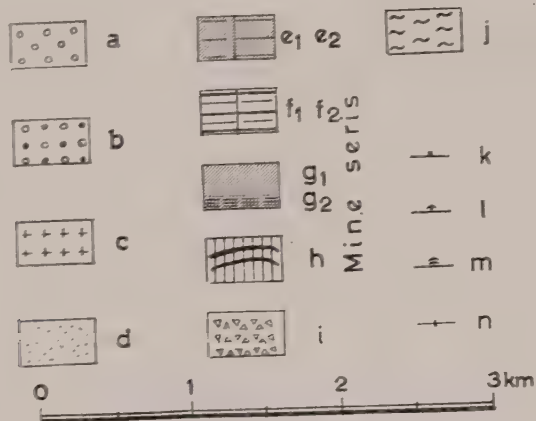
erate, i: Takago conglomerate, j: Palaeozoic crystalline schists, k: dip 0-30°, l: 30-60, m: 60°-80°, n: 80-90°.
Ai: Aisaka, Hi: Hiziji, Hs: Higashi-shimozu, Ka: Kamosho, Kb: Kibeta, Kj: Kaji, Ok: Okubata, Ts: Tsubuta, Ak: Akaiwa.

ters as the three types of sediments in the Momonoki formation in Mine area.

Thus the general succession of the Mine series in Asa area is in descending order as follows:

<div align="center">

Cretaceous Inkstone series
</div>

·················(unconformity)·············

5.	Neritic Kamosho formation	500 m thick
	(Western part: brackish Hikiji beds)	
4.	Paralic (?) Yamanoi formation (rhythmic)	1100 m
3.	Neritic Nakatsuka formation	800 m–1200 m
2.	Limnic Kajiura formation	
	2b. Idenoue delta	500 m–100 m
	2a. Akaiwa coal measure rhythm	700 m–200 m
1.	Brackish (?) Takago formation (basal cg.)	?

·················(unconformity)·············

<div align="center">

Metamorphosed Palaeozoic rocks.
</div>

2. Takago conglomerate (DOI & OKUBO, in KOBAYASHI et al. 1939)

Covering the "Sangun-schists" unconformably, the conglomerate crops out at Go (6 km to the south of Asa) on the eastern side of the estuary of the Asa river. Since its exposures are restricted and interrupted by the Inkstone series and Tertiary rocks, the true thickness of the formation is unknown. It contains angular fragments of Palaeozoic shale and sandstone, but no phenoclast of schists. It is massive, nonstratified and filled with muddy substance. It looks similar to the basal part of the Hirabara formation in Mine area in constituents and mode of sedimentation. It is presumable that the conglomerate was accumulated rapidly in the local depression. However, it is peculiar that the schistose rock is absent in this conglomerate, notwithstanding the fact that the conglomerate overlies the "Sangun schist". The fact may depend upon the sedimentary as well as palaeogeographic conditions.

It is true that the base of the Mine series is here schistose, but the grade of metamorphism is very low, seeing that pebbles of almost non-metamorphosed limestone are embedded in the "green schist". According to KIMURA (1960) schistose rocks underlie the non-metamorphosed rocks of the Yamaguchi terrain in this region. Therefore the "schist" at Go may belong to a certain 'upper' member of the metamorphic complex, where the grade of metamorphism is low. It is suggestive that the grade is low near the boundary between the metamorphosed and non-metamorphosed rocks. The constituents and texture of the conglomerate suggest that there were steep relieves composed of the non-metamorphosed rocks around the basin. These rocks were exposed on the land, while the metamorphic rocks in the basin. It is presumable that the metamorphic and non-metamorphic rocks were irregularly distributed in the boundary zone between the metamorphosed and non-metamorphosed complex. Another interpretation is that metamorphosed and non-metamorphosed rocks are alternated in this area by intense imbrication. Such structural patterns are possible in this area, because the area lies in the boundary region between the non-metamorphosed Yamaguchi terrain and the Motoyama metamorphosed zone. If so, it is presumable that the basin in

the metamorphic zone was surrounded by the land of non-metamorphic rocks. At all events, the Takago conglomerate received angular and ill-sorted pheno-clasts only from the non-metamorphosed zone. It is a kind of "eckigen Schotter" indicating unstable condition of the basin as well as steep relieves around it.

Since the Takago conglomerate is barren of marine fossils, its age and sedimentary condition are open to question. However, the stratigraphic rela-tion of the strata suggests that it may not be older than the Takiguchi age, because the Nakatsuka formation is coeval to the Momonoki formation in Mine area. It may be correlated to a certain horizon of the Takiguchi or Hirabara formation of the Mine area, after the building of the topographic relieves in the Omine phase of orogeny.

It was once considered to be coeval to the Atsu series by HASE (1947, 51), because he correlated the Nakatsuka formation to the Hirabara formation in Mine area. But the palaeontological studies clarified the Nakatsuka to be younger than the Hirabara age (TOKUYAMA, 1959b), because the Nakatsuka carries *Halobia aotii* and *Asoella*, which the latter is a subgenus of *Eumor-photis* widely distributed in the upper Carnic and Noric, and common in the Aso formation in Mine and the *Myoconcha* bed in the upper Kochigatani series of Sakawa.

3. Kajiura formation. (DOI & OKUBO, 1939)

It is distributed in the northern half of the Tsubuta peninsula on the western side of the Asa river. Its base is unexposed, because the lower part of the formation, i.e. the southern part of the peninsula, is overlain by the Inkstone series. Since the Takago conglomerate and the Kajiura formation are isolate, their true relation is unknown, but the two formations are pro-bably successive as known by the stratigraphic as well as sedimentologic studies.

It is divisible into two members, namely, the lower rhythmic alternation of the Akaiwa coal measures and the Idenoue fanglomerate. They are com-parable with the Mugikawa coal measures and Momonoki delta of the Momo-noki formation in Mine area in constituents and sedimentary structures.

3.1. Akaiwa coal measures (=Akaiwa alternation by DOI & OKUBO, 1939, Hira-matsu and part of the Idenoue formation by HASE, 1947)

It is distributed in the northern half of the Tsubuta peninsula on the western side of the Asa river. Its thickness attains 700 m along the Akaiwa coast, but 300 m in the middle part of the peninsula and less than 100 m at Okibe in the east.

Along the Akaiwa coast crops out its typical section. It is composed of numerous rhythmic beds of the Mugikawa type. It is an incomplete and irregularly bedded alternation, consisting of three members. The lower mem-ber is a massive and coarse sandstone, sometimes conglomeratic; the middle member consists of alternations of medium and fine sandstone; the upper mem-ber includes alternations of fine sandstone, shale and coal or carbonaceous shale.

The middle and upper members are thicker than the lower. The proportion of the three members and the thickness of each rhythmic bed are variable. The coal measures are irregularly bedded.

The first cycle is about 170 m thick, characterized by relatively thick lower member and poor coaly deposits in the upper member. The middle cycle, about 300 m thick, includes a coarse but relatively thin conglomerate (about 30 m thick) and characterized by the thick middle part (about 200 m). It contains fairly good coaly substances in the upper member (60 m). The third cycle is composed of a thin and fine lower member (20–30 m thick) and a thick and rhythmic upper member. It contains 3 groups of coal seams, which are intercalated by muddy and sandy materials. A coal seam is sometimes 2 m thick and of fairly good quality, but it suddenly thins out laterally. In short, coals are embedded as small lenses in the alternating beds of fine sandstone and mudstone.

Coaly layers as well as detritic beds diminish eastwards and thin out suddenly to the east of Okibe. The total thickness of the formation is about 250 m in the middle part of the peninsula, 1.2 km to the east of the Akaiwa coast. There coal seams of the second cycle are almost replaced by coaly shale, and those of the third cycle are thinner and worse than those along the Akaiwa coast. Quality of a coal seam is worse in the middle part of the peninsula than at Akaiwa, although three groups of coal seams at Akaiwa are enumerated there. Coarse sandstone layers are, however, diminished in thickness and coarseness. Further to the east, at Okibe, only some traces of coal seams are recognizable. The total thickness of the formation is less than 100 m.

Constituents of conglomerate and sandstone in this bed are similar to those found in the Momonoki formation in Mine area.

Figure 9. Three columnar sections of the Kajiura formation.

1: columnar section along the Akaiwa coast, 2: central section of the peninsula, 3: Kibeta section.

3.2. Idenoue delta (Part of the Idenoue formation by HASE, 1947)

Overlying the Akaiwa coal measures, the deltaic sediments are distributed from the western coast to the central part of the peninsula. They contain 3–4 layers of deltaic sediments. Here the "Idenoue delta" is defined as deltaic deposits, including fore-set as well as bottom-set beds of deltas. Total thickness of the formation is 550 m along the coast. It is composed of several layers of fore-set beds and bottom-set beds; coal seams contained. The cross-bedding of the fore-set bed is well exposed along the Akaiwa coast, which suggests the stream-direction to be W to E. A fore-set bed is 70 m at the

thickest. It is distributed between the coast and middle part of the peninsula, where fanglomerate diminishes in coarseness and thickness, and the fore-set bed is replaced by the bottom-set bed. The latter is thinner than the former and includes a coal seam in the middle. It is relatively uniform in thickness and quality.

In comparison with the deltaic or shooting sediment of the middle Momonoki formation, the single fore-set bed of the Idenoue delta is thinner than that of the Mine area, but coal seams in the bottom-set bed are thicker and of better qualities than in the Momonoki formation. The coal seam is intercalated in coarse and medium sandstone in Asa, but it is intercalated in conglomerates of the lateral facies as well as the bottom-set bed of the delta in Mine. Further to the east, the sandstone becomes finer and thinner, and the bottom-set bed disappears at Okibe.

3.3. *Kajiura formation in general*

The Kajiura formation, including the two members of Akaiwa and Idenoue beds, is thick on the west coast, but suddenly thins out toward the middle or eastern part of the Tsubuta peninsula. The rhythmic sediments of the Akaiwa coal measures as well as the deltaic ones of the Idenoue member are similar to the Mugikawa coal measures and Momonoki delta in Mine area in constituents, sedimentary structures and successions. It is evident therefore, that the sediments of the Kajiura formation was produced by fluvial shooting as in the Momonoki formation. Constituents of conglomerate and sandstone suggest that the provenance of the Kajiura sediments lies in the same zone as that of the Momonoki stage, because they are composed of fragments of porphyrite, granite, andesite and schists, beside Palaeozoic rocks. The thickness variation and cross-bedding in the fore-set bed of the Idenoue delta, as shown in the columnar section, evidence the detritus to have been transported from the west. The axial zone of the Akiyoshi folded mountains was probably located in the western side of the basin.

4. *Nakatsuka formation* (HASE, 1947)

Overlying the Kajiura formation, it is distributed in wide areas from the west coast to the east of Aisaka, through Nakatsuka, Okibe, Torigoe, Higashi-shimozu, Nishimi pass and Zenihara.

It is about 700 m thick along the west coast and 1200 m at Kibeta. In the eastern part its thickness is unknown, because the southern part (lower part) of the bed is capped by Tertiary rocks. The formation, however, becomes thinner to the east, as known by the general succession. It is fossiliferous in two horizons, namely the lower *Halobia*-shale and the upper *Asoella* shale. They are correlated to either the middle or upper Carnic stage.

The Nakatsuka formation begins with the transgression of the *Halobia*-shale. It is as thick as 300 m at Okibe and Kibeta areas, but diminished to the west and disappears near the west coast. *Halobia kawadai*, *H. aotii*, and *H. molukkana* beside *Oxytoma* cfr. *subzitteli* were collected at several localities

between Okibe and the west coast. *H. kawadai* occurs also in the upper Hirabara formation of Mine area; two other species are common in the *Halobia-Tosapecten* bed of the Kochigatani series, but absent in the Hirabara formation. *H. aoti* occurs commonly in the *Asoella* shale of the upper Nakatsuka formation. It is therefore suggestive that the *Halobia*-shale of the Nakatsuka formation is younger than the Hirabara stage, although it is coeval to the *Halobia-Tosapecten* bed of the Kochigatani series. The *Halobia*-shale is followed by a massive sandstone, relatively well sorted and rounded, and then by alternating beds of graywacke and shale. They show alternation of graded bedding, although not regular. After the deposition of 600 meters' sandstone and grade beds comes once more a shaly bed, including small patches of shale and nodules. It is 100-200 m thick and yields *Eumorphotis* (*Asoella*) *nakatsukensis* and *Halobia aotii*, beside myacids, at several localities between Morimoto (near the west coast) and Higashi-shimozu (south of Asa). The shale is traceable further to the east as far as Aisaka, where it yields *Halobia aotii* sporadically (KOBAYASHI & AOTI, 1943). *Asoella* is a subgenus of *Eumorphotis*, extensive in upper Carnic and Noric. It is common to the middle Aso formation in Mine, although *nakatsukensis* is specifically distinguishable from the two Aso species. *Asoella* is also reported from the upper Kochigatani series at Sakawa. It is proved that the Nakatsuka formation is younger than the Hirabara formation and older than the middle Aso formation. Therefore it is coeval to a part of the *Halobia-Tosapecten* bed of the middle Kochigatani series and Momonoki formation in Mine, although the Momonoki is limnic.

Ecologically the two fossil beds of the Nakatsuka formation, namely the lower or *Halobia-* and upper or *Asoella*-bed are neritic sediments. Sandstone and alternation between the two beds are also neritic, because sandstone is rolled. The graded beds and angular fragments of shale in the graywacke suggest a condition of rapid accumulation, probably due to subsidence.

5. *Yamanoi formation* (YOKOYAMA, 1891)

Overlying the Nakatsuka formation the Yamanoi formation is distributed in wide areas between Habu, on the west coast, and north of Funaki, through Yamanoi, Asa and Okubata. It is about 1300 m thick in the western part and 1000 m thick in the eastern part.

It reveals monotonous and uniform rhythmic alternation, made up of coarse sandstone (2-5 m thick) and an alternation of mudstone and shale (5-7 m) in the western part. A unit of the rhythm is 5-10 m thick and the alternation exceeds the sandstone member in thickness near Yamanoi. The shaly beds of the alternation yield plant fossils, which were described as " Rhaetic Yamanoi plants " by YOKOYAMA (1891) and OISHI (1933; OISHI & TAKAHASHI, 1936). Alternations are sometimes carbonaceous but no coal seam is found among them. The alternating beds may be regularly or irregularly bedded. They are commonly made up of a symmetric cycle, consisting of 3 members. The lower member is composed of alternation between medium and massive and stratified sandstones; massive sandstone is somewhat muddy; the middle part

of carbonaceous mudstone and shale, containing plant fossils in lower and
upper beds; the upper member consists of medium sandstone and fine sand-
stone. The middle part is made up of symmetric rhythms of sandy shale and
shale, showing similar change in grain size, as alternation of the inundation
stage (Mitsusugi sandstone).

The sandstone member of the rhythmic bed is similar to the Momonoki
and the Enokawara formation in constituents and texture, although sandstone
is somewhat more abrabed and rolled in Asa than in Mine. Constituents and
textures of the sandstone are similar to those found in the southern off-shore
part of the Aso formation. The alternation and sandstone of the Yamanoi
formation show an off-shore equivalent of the Momonoki. They are similar
to rhythmic sediments of the Enokawara formation in the poor development
of coal and sandstones, somewhat influenced by current.

In the Yamanoi formation sandstone is more influenced by water currents
and bearing higher maturity in the eastern than the western part. The coaly
substance diminishes to the east. The rhythmic sediment of the Yamanoi
formation is replaced in the east by a characteristic sediment, consisting of
the alternating beds between light and dark coloured sandstones. The alter-
nation of two sandstones is found in the east of Asa, between Kyomasa and
Okubata. A unit of the alternation is 0.5–1.5 m thick. The alternating bed
is made up of 3 members. The lower member (2/5 of the total thickness of
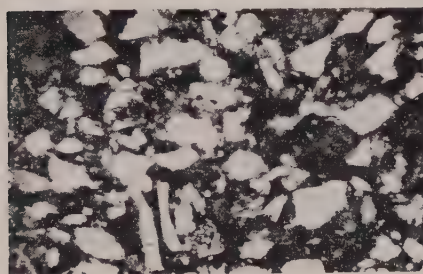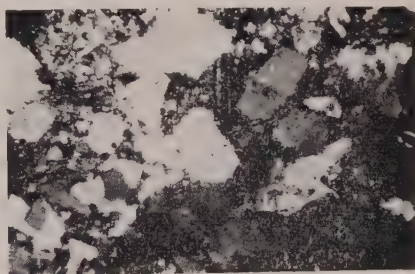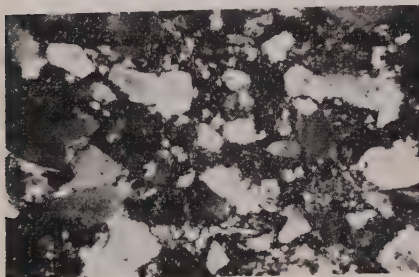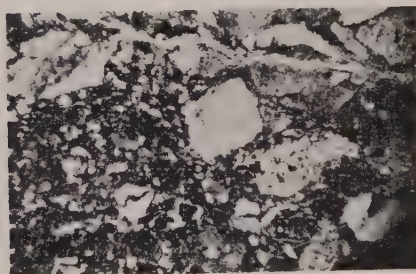
Figure 10. Sandstone of the Yamanoi formation

1. Carbonaceous sandstone (lower member) of a rhythm at Okubata, Asa.
2. "Clean sandstone" (upper member).
3. Cherty sandstone, at Aisaka, Asa.

the bed) includes black carbonaceous sandstone, containing mica flakes and
and carbonaceous matrices (fig. 10-1a).   This grades up into the middle member
(about 2/5).   It is composed of sandstone with fine striation.   The sandstone
contains carbonaceous substance less than the lower member.   It is intercalated
by thin and black bands, containing carbonaceous matter.   The middle member
merges into quartzose and "clean" sandstone of the upper member (fig. 10-2).
The sandstone is composed of quartz, feldspar (quartz > feldspar) and a few
fragments of rocks.   They are fairly well rounded and filled with cherty
matrix.   This represents an off-shore equivalent of the Aso sandstone (pl. XVII),
because it has andesite fragments as well as microcline in the west at Yamanoi.
The maturity of sandstone becomes gradually higher to the east.   At Kuchino-
tsubo, 10 km to the ENE of Asa, the sandstone is represented by quartz sand-
stone if not orthoquartzite.

In comparison with the two types of sandstones, the constituents of pheno-
clasts are quite identical between the upper and lower members of the alter-
nation. The two sandstones are nearly same in proportion of quartz and feld-
spar, if matrices are ignored.   The difference between the two sandstones lies
in muddy or carbonaceous substances in matrix.   The matrix of the lower
member is coaly and muddy, provided with minute mica flakes, while the
matrix of the upper member is made up of chert or cryptocrystalline quartz.
The relative volume of matrix to the phenoclast is larger in the lower member
than the upper.   Facies change from the lower to the upper member is gradual,
but that from the upper to the lower member of the next rhythm is sudden.
In other words, the rhythm begins with a sudden shooting of carbonaceous
and muddy substances and terminated with its gradual disappearance.

In the horizontal distribution, carbonaceous as well as muddy substance
increases to the west.   At a point north of Aisaka, 2 km to the west of Oku-
bata, the bed contains coarser carbonaceous sediments and more numerous
mica flakes than at Okubata.   The bed is replaced by the rhythmic alternation
of muddy sediments further in the west near Yamanoi, where sandstone con-
tains a few andesitic fragments beside microcline.   It is evident that the alter-
nating beds between the sandstones at Okubata is an off-shore equivalent of
the Yamanoi rhythm, which the latter is an off-shore equivalent of the Momo-
noki rhythm.   Therefore the appearence of coaly matter in the Okubata
rhythm indicates a shooting phase of terrigenous matter.   If the Momonoki
rhythm is explained by the sudden fluviatile shooting, followed by the eleva-
tion of the hinterland, the rhythmic alternation of the Okubata sandstone can
also be explained in the same way.

The upper part of the formation is marked by a thin liparitic tuff.   It is
1 m thick at a locality 1.5 km to the NE of Asa.

The Yamanoi formation lacks marine shells, but it is apparent that water
was agitated in the Yamanoi basin.   Therefore the formation is probably
paralic.   This is supported by the fact that no marine shell is kept in the
massive sandstone of the neritic Mitsusugi sandstone of the lower Aso forma-
tion.   The water current may have fractured fossils, if present, since sediments

had been reworked for many times before settling.

6. *Kamosho formation* (KOBAYASHI, 1935)

It is distributed to the east of Kamosho and overlies the Yamanoi forma-
tion. Since it is covered by the Inkstone series in the eastern part, its upper
limit, as well as total thickness of the bed are unknown. It is as thick as
500 m on the eastern side of the Asa river.

It begins with massive sandstone, which is followed by a shaly bed attain-
ing 150 m at a point 1.5 km to the northeast of Kamosho. It contains *Monotis
scutiformis* and small *Halobia*. The shaly bed is noduliferous at first and then
micaceous and somewhat muddy, but it becomes finer and purer toward the
top. *Monotis* and *Halobia* are scattered in the lower part at two localities of
Kamosho and the eastern side of the Asa river. They suggest lower Noric
age. After the shaly bed comes a series of graywacke with shaly intercala-
tions at Shimo-takanosu. The sandstone of the bed is distinguishable from
that in the Yamanoi formation, because it is of graywacke type, containing
angular fragments of quartz, feldspar and shale as in the Jito sandstone in
Nariwa area (1960e). On the other hand the Yamanoi sandstone belongs to
the arenite-quartz-sandstone series, as in the Mitsusugi sandstone in Mine area.

Interrupted by the Inkstones, the bed crops out once more in the western
part of Asa at Hikiji and Kataoka, where no *Monotis*-shale is inserted but
Estherians are reported (KOBAYASHI, 1952). The bed was therefore called
"Hikiji formation". It may be a non-marine or near-shore equivalent of the
Kamosho formation, composed of relatively massive sandstone with intercala-
tions of several mudstone layers.

Recently *Monotis scutiformis* was reported by HASE* in Iwakuni district
in the eastern part of Yamaguchi prefecture. The *Monotis* bed at Iwakuni
shows similar lithology and fossil assemblage as the Kamosho formation.
Therefore the Kamosho formation is considered to be uniform through wide
areas. If the upper part of the Aso formation in Mine area is coeval to the
Kamosho formation, there will be either *Monotis* bed or the noduliferous and
micaceous shale like Kamosho formation, but they can not be found in Mine
area. On the other hand the Kamosho formation yields neither *Asoella*, nor
Rhynchonella. The two fossils are indices of the Aso formation. Therefore it is
obvious that the Kamosho formation is younger than the Aso formation. The
Aso formation may be roughly correlated to the Yamanoi formation.

7. *Correlation*

The Mine series in Asa area is made up of 5 formations. They are Takago,
Kajiura, Nakatsuka, Yamanoi and Kamosho formations in ascending order.
Among them marine fossils are found in the Nakatsuka and Kamosho forma-
tions but none in the Takago, Kajiura and Yamanoi formations.

The Nakatsuka formation includes two fossil beds. The lower one carries

* Transactions and Proceedings of the Palaeontological society of Japan, N.S., no.
35, 1959; Ibid., no. 42.

H. kawadai, H. aotii, H. molukkana beside *Oxytoma subzitteli.* Among them *H. aotii* is so abundant that the lower fossil bed is called *H. aotii*-zone. *H. kawadai* is distributed widely in Japan. It is found in the middle and upper Hirabara formation in Mine, lower Nabae series in Maizuru area and lower and middle Kochigatani series in Sakawa, Sakuradani and Kuma areas (TOK., 1959b). The fossil assemblage of the bed suggests the zone to be younger than the Hirabara formation and coeval to the middle Kochigatani series. The upper fossil bed of the Nakatsuka formation is represented by the *Asoella nakatsukensis*-zone. It carries also *H. aotii* rarely. *Asoella* is known in the Aso formation in Mine and the upper Kochigatani series, although the Aso and Kochigatani species are distinguishable from *nakatsukensis* specifically. On the other hand no typical *aotii* is found in the Aso formation, although fragments of *H.* aff. *aotii* are found in the lowest *Tosapecten* shale of the Mitsusugi sandstone or the lower Aso formation. Therefore it is certain that the *Asoella nakatsukensis* bed of the Nakatsuka formation is older than the *Asoella* bed of the Aso formation.

Finally the Nakatsuka formation is coeval to the major part of the Momonoki formation in Mine, although the Momonoki is limnic and carries no marine shells. If so, the larger part of the limnic Kajiura formation is correlated to the neritic Hirabara formation in Mine. So is the Takago conglomerate to the Takiguchi, if not to the lower Hirabara formation.

The *Monotis scutiformis* horizon of the Kamosho formation is younger than the Aso formation. The time gap between the *Asoella* bed in Mine and the *Monotis* bed in Asa may be slight, because the Rhychonelloids of the Aso formation indicate lower Noric (1957). *Monotis scutiformis* is also considered to be lower Noric. It is older than the *Monotis ochotica* zone (ICHIKAWA, 1958). Thus the larger part of the Aso formation is proved to be coeval to the Yamanoi formation and they are characterized by sediments on the stable shelf. The Yamanoi sediments were however, greatly influenced by the elevation of the hinterland, while those of the Aso formation is characterized by oscillatory deposits of the basin, influenced by the undulation in the basin.

IV. Mine series in Nariwa area

1. General geology

The Upper Triassic sediment of Nariwa area in Bitchu or Okayama is one of the oldest known in Japan as a mention was made of occurrence of *Monotis ochotica* and plant fossils of the Rhaeto-Liassic type. The *Monotis ochotica*-bed was first reported by NAUMANN (1885) and subsequently discussed and described by HARADA (1890), DIENER (1915) and others. Fossil plants have been described by YOKOYAMA (1905), OISHI (1931, 32, 40) and OISHI & FUJIOKA (1938). The stratigraphy of the Triassic sediment was first outlined by OTSUKA (1896), and areal survey of the Triassic formations was carried out by KOBAYASHI and his students (KOBAYASHI, HORIKOSHI et al., 1937; CHO, 1939). Because "Rhaetic" plants are associated with Noric marine shells, special attention had been paid to their stratigraphic relation by many geologists (AKAGI, 1925;

SAEKI, 1930; OISHI, 1930, 31, 32, 38; NAKAZA & WADA, 1931; YABE & MABUTI, 1934; KOBAYASHI et al., 1937), until its Noric age was ascertained by KOBAYASHI (1938). As explained in the preceding chapters, the so-called " Rhaeto-Liassic " flora is contained in the Ladino-Carnic and Carno-Noric sediments of the Atsu and Mine series in Atsu, Mine and Asa areas of Japan. Further investigations on stratigraphy, palaeontology as well as tectonics in Nariwa area were made lately by KAWAI (1951), KOBAYASHI & ICHIKAWA (1952), NAKANO (1952, 57), TERAOKA (1959), NAKAZAWA (1959) and TOKUYAMA (1960d, e).

The Triassic sediments of Nariwa area overlies the phyllitic Palaeozoic rocks with unconformity on the south side and partly overlain by the Cretaceous Inkstone series on the northern side, as in Asa area in Prov. Nagato. They are covered on the northern side by a " Decken scheet " of non-metamorphosed Palaeozoic rocks of the para-Akiyoshi facies, as has been reported by OZAWA (1925) and KOBAYASHI (1937, 41).

They reveal a broad syncline in the eastern part around Hinabata (1 km to the south of Nariwa). Approaching the Oga-thrust, however, they repeat minor foldings and thrustings with the axes subparallel to the thrust front in the western part near Oga (KOBAYASHI, 1937; TOKUYAMA, 1960e). Thus the Triassic formation was disturbed by the orogenic movement of the Oga phase (KOBAYASHI, 1941).

Although the Triassic sediments are disturbed, precise observation enabled me to obtain their complete succession. The unconformity at the base is exposed at several localities on the south side of the Triassic basin. Commencing with this base, coarse grained and terrigenous sediments are accumulated as thick as 2300 m. They are divisible into 3 formations.

The lower or the *Mogamiyama formation*, 500 m thick, is composed of frequent rhythmic alternations of sandstone, shale and coal. It includes a fanglomerate in the upper member, called *Mogamiyama delta*. The middle or the *Hinabata formation*, 500 m thick, consists of rhythmic sediments of sandstone and alternation of mudstone and shale including fossil plants. They are similar to those of the Mogamiyama formation, but reveal more or less stable condition than the Mogamiyama rhythms. The Mogamiyama and Hinabata formations are limnic. The rhythmic sediments and a fanglomerate of the two formations are similar to those of the Momonoki formation in Mine area not only in their constituents, but also in the macroscopic as well as microscopic textures. Most of them are produced by fluvial shooting and derived from the elevating axis of the Akiyoshi folded mountains on the northern side. The upper or the *Jito formation* is marine and yields embayment or near-shore shells from the lower member and *Monotis ochotica*, a nautiloid and an ammonite, from the upper member, which is considered to be a neritic or open-sea sediment.

Recently another marine formation was found at Kyowa in the southwestern part, which is called *Kyowa formation* (NAKANO, 1952). It is isolated from the above three successive formations by faults. *Minetrigonia* and *Palaeopharus* of the formation suggest it to be lower to middle Carnic. Its

stratigraphic relation to the three successive formations is not determined, be-
cause it is isolated from them by faults. The Kyowa sediments, however,
reveal a fore-runner of the Mogamiyama and subsequent formations, because
it contains coaly material in the upper part. Therefore the Triassic of Nariwa
begins with the Carinic Kyowa formation and terminates with Noric Jito
formation. They are contemporaneous to the Mine series in Mine and Asa
areas in Nagato, although there is no *ochotica*-bed in Nagato. The Mogami-
yama and Hinabata formations are similar to the Momonoki and Kajiura
formations not only in lithology, but also in sedimentary conditions. Therefore
the Upper Triassic sediments of Nariwa area (Nariwa series by KOBAYASHI)
can safely be correlated to the Mine series.

In this paper the "Mine series" includes Upper Triassic sediments of
the three areas, namely Mine, Asa and Nariwa in West Japan.

2. *Kyowa formation* (NAKANO, 1952)

The Kyowa formation is less than 100 m thick and crops out in a small
valley near Onji in Kyowa district, about 15 km to the SW of Nariwa. It is
isolated from the younger formations by faults. It consists of three members:
The lower member is about 30 m thick and contains medium to fine sand-
stone and mudstone, with pebbly layers, containing chert and shaly pebbles.
The middle member is 35 m thick, consists of sandstone and mudstone, con-
taining five pelecypod species, which are identified to those from the Hirabara
formation in Mine and Nabae-Heki formations in Maizuru area (NAKANO, 1957).
The faunule suggests the member to be coeval to the upper Hirabara forma-
tion in Mine, the middle Kochigatani series in Sakawa or the lower to middle
Nabae series in Maizuru. These pelcypods are on the whole embayment
inhabitants. The upper member, more than 30 m thick, is composed of alter-
nating beds of massive gray sandstone, bituminous mudstone and shale, con-
taining a coal seam and plant bed in the upper part. Carbonaceous rhythmic
beds, appearing first in this stage, are transition between the neritic Kyowa
and limnic Mogamiyama formations.

According to NAKANO (1957) the Kyowa formation includes *Minetrigonia
katayamai, Oxytoma subzitteli, Bakevelloides hekiensis, Lima yataensis* and three
varieties of *Palaeopharus maizuruensis*. *Minetrigonia* and *Oxytoma* are common
to the Hirabara formation in Mine area and the lower and middle Kochigatani
series, but very rare or absent in the Nabae and Heki faunas in Maizuru area.
The two species of *Lima* and *Palaeopharus* are known from the Nabae and
Heki faunas, but not from the Mine and Kochigatani faunas. *Bakevelloides
hekiensis* is common all in the Hirabara, middle and lower Nabae and Heki
formations, but absent in the Kochigatani series. Therefore the Mine-Kochi-
gatani and Nabae-Heki faunas are linked by the Kyowa fauna, although it is
more closely related to the latter than the former.

The *Minetrigonia-Palaeopharus* bank is found in coarse and feldspathic
sandstones in the Hirabara formation, but it is composed of medium and some-
what muddy sandstone in the Kyowa formation and similar to that in Heki

and N3-bed of the Nabae series in lithology.

Seeing that there is no shooting of coarse sediments in the *Minetrigonia* bed of the Kyowa formation, the basin was yet stable in this stage, as in Maizuru region. Bituminous sediments and coal seams in the upper member of the formation indicate the basin becoming shallower in the later stage. The alternating beds of the rhythmic sediments in the same member show the contemporaneous oscillations of the basin.

Since the Kyowa formation is isolated from the coal measures of the Mogamiyama formation, the stratigraphic relation of the Kyowa and Mogamiyama formation is uncertain. The upper Kyowa formation is probably non-marine and contains rhythmic as well as coaly sediments; and its ligthology is not much different from the Mogamiyama formation, which is characterized by limnic and rhythmic alternation, containing coal seams. Moreover, the lower member of the Mogamiyama formation received its sediments from the non-metamorphosed rocks as in the Kyowa formation. Therefore the stratigraphic positions of the Kyowa and Mogamiyama formations are very close, if not the two are conformable. On the other hand no marine band is intercalated among the Mogamiyama and Hinabata sediments. Therefore the Kyowa formation may be a subjacent bed to the Mogamiyama and Hinabata formations, rather than a contemporaneous bed.

2. *Mogamiyama formation* (TERAOKA, 1959)

Overlying the weakly metamorphosed rocks, phyllitic rocks and non-metamorphosed rocks of the base unconformably, the Mogamiyama formation is distributed along the southern border of the Mine series from Shodera (W) to Otani (E) through Jobo, Misawa and Kurohagi. It attains 750 m near Kurohagi, but less than 400 m in the western part near Jobo. It is broadly folded in the eastern part of the Hinabata, but intensely thrust in the western part at the southern front of the Oga-thrust (TOKUYAMA, 1960e).

In Hinabata area it is divisible into two members:

The lower member attains 450 m near Kurohagi and contains monotonous rhythmic alternations. Each of the rhythmic alternation is composed of two parts; the lower part includes thick, pebbly and coarse sandstone of the Momonoki type in Mine area, and so does the upper relatively thin layers of fine sandstone and mudstone. Among the pebbles of conglomerate, chert is most common, but shale, sandstone, porphyrite and other pebbles are insignificant. Neither schistose nor gneissose rock is found among the pebbles. The sandstone is composed of numerous rock fragments of andesite (attaining 40%), sedimentary rocks (less than 15%) and schist (less than 5%), besides granite (40–50%) (TOKUYAMA, 1960d). The Mogamiyama sandstone (fig. 11: 1-3) is characterized by relatively angular fragments, numerous unstable rock fragments and paucity of matrix. Therefore the rock is extremely immature and carries original voids (fig. 11-1), although they are filled with secondary precipitates. It is very similar to the Momonoki sandstone in Mine in constituents and texture (A-sandstone in 1960d). Seeing that the constituents have

not been influenced by currents, the Mogamiyama formation may be limnic
as the Momonoki formation. Neither schistose, nor gneissose rock is found
as pebbles, but they are found in rock fragments of the sandstone. It is pre-
sumable that the basin received sediments from the elevating axial zone of
the Akiyoshiiden in this stage, as in the middle and upper Mine series in
Mine area. The provenance may have been in the northern side, instead of
the southern, because there is neither such granitic rocks nor highly meta-
morphosed rocks as in the rock fragments of the Mogamiyama sandstone, in
the southern part of the basin, although the Mogamiyama formation lies on
the weakly metamorphosed rocks.

The rhythmic sediments often contain plant fossils in shaly and muddy
beds, but rarely carry coal seams. Toward the upper part of the member
coarse and pebbly sandstone becomes finer while the shaly part becomes more
carbonaceous.

In the western part of the southern front of the Oga-thrust, sediments
are more or less finer than in the Hinabata basin, and rhythmic sediments are
more uniform or monotonous than in Hinabata.

The upper member of the Mogamiyama formation includes coarse and thick
conglomerate in Hina area. The conglomerate thins out suddenly to the west
near Misawa, where several shaly and carbonaceous intercalations of bottom-
set bed or lateral facies of a delta are embedded in the conglomerate. Neither
the conglomerate, nor shaly intercalation is present in the western part or the
southern front of the Oga-Decke.

The conglomerate contains no shaly layer in the eastern part of Hina
area. It is coarser to the north and finer to the south. Pebbles are rounded
and attain 15 cm in diameter. They contain numerous granitic rocks and few
chert-, shale- and sandstone-pebbles. The grain size distribution indicates the
provenance lying on the north side. This conglomerate is relatively massive
and lacks any characteristic structure of "fore-set" bed. It includes either

9. conglomerate, pebbles are rounded and well stratified
8. coal seam
7. coaly shale
6. bituminous shale
   6c. with mica flakes
   6b. fine and compact black shale
   6a. bituminous sandy shale
5. medium sandstone, relatively well sorted
4. black fine sandstone with feldspar fragments
3. conglomerate with rounded pebbles (2–3 cm) of por-
   phyrite, hornfels, subangular pebbles of shale and
   stratified.
2. sandy shale, grey and well stratified.
1. conglomerate, with rounded pebbles (max. 12 cm) of
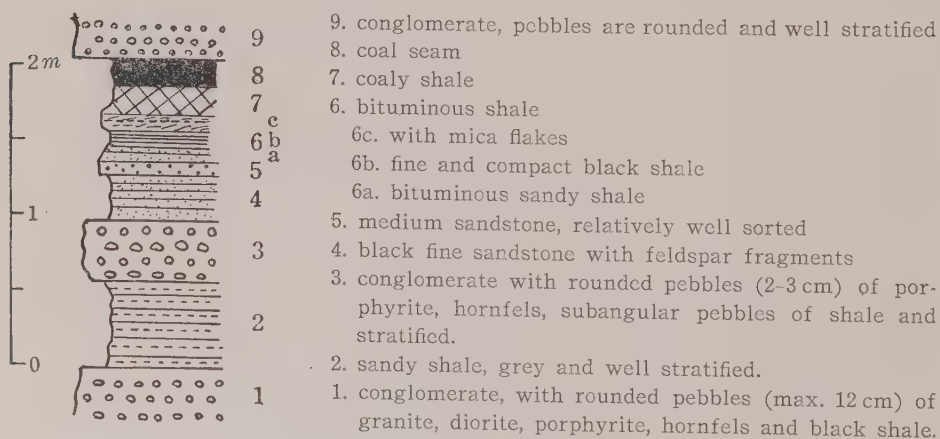   granite, diorite, porphyrite, hornfels and black shale.

Figure 11. A shaly intercalation in the "bottom-set" bed
of the Mogamiyama delta. (See also plate XVI).

bottom-set or the lateral facies of a delta. Shaly, muddy as well as carbonaceous intercalations are found in the conglomerate layer on the western margin. They belong to the "bottom-set" bed of a delta. An example of the intercalation is shown in figure 11. This bed is fairly extensive from north to south along the margin of the conglomerate, but suddenly thins out toward the west. It is evident that the shaly intercalation is closely related to the conglomerate genetically. The conglomerate and the intercalation suggest the fluvial shooting of the Nagelfluh type, as in the Momonoki delta in Mine area and the Idenoue delta in Asa area.

4. *Hinabata formation* (TERAOKA, 1959)

Overlying the Mogamiyama formation, the Hinabata formation is distributed in Hinabata and the southern front of the Oga thrust. It is more than 500 m thick in Hinabata area. Its thickness is indeterminable in the southern front of the Oga thrust, because the formation is intensely disturbed.

It is composed of rhythmic alternations of sandstone and shaly sediments as in the lower Mogamiyama formation. They are somewhat muddy in the eastern or Hinabata area and bear coal seams in the western part or the southern front of the Oga thrust, near Oga and Shodera.

The aspects of the Hinabata rhythm are similar to those of the Mogamiyama rhythm, but somewhat different in the lithology of the sandstone and alternation. A rhythm in the middle Hinabata formation, exposed at Minami, has the following succession (in descending order):

8. 0.35 m : frequent alternation of sandstone and shale
7. 0.15 m : stratified medium sandstone with fine (2-3 mm thick) banding
6. 1 m : compact black shale
5. 1.5 m : alternation of sandstone and shale, well stratified
4. 0.4–0.6 m : muddy (lower) and carbonaceous (upper) shale with plant fossils in muddy bed and coal seam in the upper bed
3. 0.3 m : frequent alternation of coarse and banded sandstones
2. 0.2 m : medium sandstone with muddy matrix
1. 5–6 m : massive and coarse sandstone; its lower part is arenitic, but the upper part is somewhat muddy

The 5th member of the alternation indicates warping of the basin and the 6th member represents the inundation phase of the oscillation. Among the rhythmic sediments of the Mogamiyama formation no such facies as 5th or 6th is intercalated.

Sandstones of the Hinabata formation (1960d, plate) are somewhat rounded and sorted. They include three kinds among rhythmic sediments. The lower part of the sandstone member is arenitic, with little matrix. It belongs to the same arenite as the Mogamiyama sandstone, but the volume of andesites is less in it than in the Mogamiyama-sandstone. The middle part is characterized by micaceous sandstone, containing numerous mica flakes. The sandstone is more matured than in the lower part and characterized by more numerous quartz grains than in the lower sandstone. The upper part contains muddy sandstone, carrying muddy cementing materials.

These three types of sandstones suggest slower deposition than the Mogamiyama one because grains are abraded and sometimes they are deposited together with muddy substances and mica flakes. Thus the shaly as well as sandy members were probably deposited more slowly and under more stable condition than the Mogamiyama sediments, although the Mogamiyama and Hinabata sediments are similar to each other in the constituents and textures. The sedimentary condition appears to be more stable in the upper part than the lower part of the Hinabata formation. The shaly intercalations contain many well preserved fossil plants in the eastern part near Hinabata, and coaly material in the western part near Oga and Shodera. Since the conglomerate of the upper Mogamiyama formation disappears in the western part of the basin, lithologic change from the Mogamiyama to the Hinabata formation is gradual. There is no sharp boundary between the two formations in the western part, although the lower part or the equivalent of the Mogamiyama formation is less carbonaceous than the upper part or the Hinabata formation.

5. *Jito formation* (OISHI, 1931)

The Jito formation overlies the Hinabata formation conformably and is more than 1000 m thick. It is somewhat bituminous in lower beds, but purely marine in the upper horizon. Facies change from the non-marine Hinabata to the nearshore lower Jito formation is gradual in Minami and Jito areas.

At two localities, near Jito, 4 km to the SW of Nariwa and Eda, 1.5 km to the north of Nariwa, the lower Jito formation carries pelecypods, gastropods and brachiopods indicating near-shore or embayment condition. It carries *Waagenoperna triangularis, Cardinia misawensis,* "*Gervillia*" *saekii,* two gastropods, a *Dentalium* and a *Lingula* beside a cidarid spine in somewhat bituminous sediment at Jito (KOBAYASHI & ICHIKAWA, 1952). It contains *Tosapecten suzukii okadai* in muddy sandstone at Eda. A *Monotis*-bed lies about 200 m above the sandstone. The *Tosapecten*-sandstone is an embayment deposit and similar to the *Tosapecten*-shale of the Mitsusugi sandstone in Mine area (1960a, facies A), while the *Monotis* bed indicates an open sea. Here the change in lithology of sandstone and shale from the *Tosapecten* to the *Monotis* bed is gradual.

Monotis (*Entomonotis*) *ochotica* occurs at many localities, sometimes in black shale, but sometimes in sandstone. The *Monotis*-sandstone is more matured than the Hinabata sandstone (1960d). It contains sometimes subangular quartz and feldspar fragments and cherty matrices. It is a kind of subgraywacke (1960d, D-sandstone), influenced by strong current, and indicates an open-sea. It is easily distinguishable from the Mogamiyama and Hinabata sandstones (1960d, A–C sandstones) in constituents and textures. There is no such sandstone in the Mogamiyama and Hinabata formations. Therefore the sandstone of the D-type is safely referred to the Jito formation, if *Monotis* is absent in it, because there was no strong water current in the basin in the Mogamiyama and Hinabata ages. It is evident that the Jito formation is distributed widely in the western part of the basin or the southern front of the Oga-Decke,

although *Monotis* is very rare in Oga area.

Monotis ochotica is Noric and clarifies the upper Jito formation to be coeval to the Saragai formation in Kitakami and its contemporaries in the Kochigatani series in southwest Japan. Among the lower Jito pelecypods, *Tosapecten*, *Waagenoperna* and *Cardinia* are conspecific with those of the Aso formation in Mine area, which is considered Carno-Noric or lower Noric. Since the Jito formation lacks *Monotis scutiformis*, which is common in the Kamosho formation in Asa, the Jito formation is younger than the Kamosho, which the last is younger than the Aso.

6. *Correlation*

The Mine series in Nariwa area contains marine shells in two horizons. They are the lowest Kyowa formation and the top of the Jito formation.

The Kyowa formation is correlated to either the upper Hinabata formation or the lower to middle Nabae series, because *Minetrigonia*, *Bakevelloides* and *Palaeopharus* are dominant in it. The Jito formation is characterized by the *Monotis ochotica* zone but its lower member contains *Waagenoperna triangularis* and *Cardinia misawensis* beside *Tosapecten suzukii*, all of them being identical to those from the Aso formation. Therefore the *Monotis*-bed in Nariwa area may be more or less older than the *ochotica* bed in Kitakami and other regions, although it is younger than the lower Noric *scutiformis*-zone in Asa area. At all events, the Mine series of Nariwa area ranges from lower or middle Carnic to middle or upper Noric. Therefore the Mogamiyama and Hinabata formations between the two marine formations range from upper Carnic to lower Noric. The range is longer than the Momonoki formation in Mine which is middle Carnic. In Asa area marine bands of the Nakatsuka formation are intercalated between the two non-marine formations, i.e. Kajiura and Yamanoi formations. The Mogamiyama-Hinabata stage of Nariwa area includes Momonoki and Aso ages of Mine area, Nakatsuka, Yamanoi and Kamosho ages in Asa. The non-marine stage lasted longer in Nariwa than in two other areas of the Mine series. The non-marine sediments change gradually and successively from the Mogamiyama to the Hinabata stage, although the two stages are characterized by similar rhythmic sediments as the Momonoki formation in Mine. The Mogamiyama formation suggests an intense crustal movement and a narrow basin as the Momonoki formation in Mine area. The intensity of the crustal movement became more gentle and at the same time the basin may have been wider in the later stage. After the shooting of the Mogamiyama-delta, a sequence of the rhythmic sediments was accumulated. They are superficially similar to those of the Momonoki formation in Mine, Kajiura and Yamanoi formations in Asa and the Enokawara formation in Atsu, but it is somewhat different from them in the constituent and texture. Muddy sandstone and micaceous sandstone characterize the Hinabata formation, but they have not been accumulated in the Momonoki and Kajiura formations, although somewhat similar sandstone is found in a certain horizon of the Yamanoi formation. The muddy intercalation of the Hinabata formation

includes alternation of the symmetric rhythms, revealing the warping of the basin. The sandstone and alternation of the Hinabata rhythm represent a less intense crustal movement or the more stable condition of the basin than any other sediments of the Momonoki-type among the Mine and Atsu sediments in Atsu, Mine and Asa areas.

V. Mine Series in West Japan

1. Correlation

The Mine series in Mine and Asa areas in Nagato and Nariwa area in Bitchu include Carnic and Noric sediments, which are either limnic or paralic. Marine bands are found here and there among them and carry fossils in the following three facies.

1. open sea, off-shore facies....pterioid shale
2. neritic or coastal facies ....*Minetrigonia*- and *Waagenoperna*-sandstone
3. embayment facies ....*Bakevelloides-Palaeopharus* community in
                                bituminous sediments

Sediments of the first and second facies were deposited under water current, while the third indicates the stagnant water. The first facies is restricted to the transgressive facies in the Mine series and carries pterioids and off-shore shells, which are common to the contemporaneous neritic Kochigatani series in Shikoku. These shells are therefore suitable for regional correlation. Five species of *Halobia*, two of *Eumorphotis* (*Asoella*) and two of *Monotis* are arranged in descending order as follows:

8. *Monotis ochotica* ....Jito formation in Nariwa area
7. *M. scutiformis* ....Kamosho fmt., Asa
6. *Asoella confertoradiata* ....Middle to upper Aso fmt., Mine.
5. *A. nakatsukensis* and
            Halobia obsoleta....Upper Nakatsuka fmt., Asa.
4. *H. aotii* ....Lower to upper Nakatsuka fmt., Asa; low.
                                Aso fmt.
3. *H. kawadai* ....Upper Hirabara fmt., Mine; lower Nakatsuka
                                fmt., Asa.
2. *H. kashiwaiensis* ....Middle and upper Hirabara fmt., Mine
1. *H. subsedaka* ....Middle Atsu series to lower Hirabara fmt.,
                                Atsu and Mine.

The *H. subsedaka*-shale carries *H. atsuensis* and *Daonella yoshimurai* in the Atsu series and dated as upper Ladinic, if not lower Carnic (KOBAYASHI & TOKUYAMA, 1959; TOKUYAMA, 1959b). It carries *Mysidioptera* in the lower Hirabara formation and considered lower Carnic (TOK., 1960b). *H. kashiwaiensis* was originally described from the *Oxytoma-Mytilus* sandstone at Kashiwai (KOBAYASHI & ICHIKAWA, 1949), and subsequently from the middle and upper Hirabara formation in Mine (TOK., 1959b). The *kashiwaiensis* horizon in the Mine series is correlated to the lower Kochigatani series. *H. kawadai* is most extensive among the Halobiidae of Japan. It occurs in the middle and upper Hirabara formation in Mine, lower Nakatsuka formation in Asa, lower Nabae

series in Maizuru area, *Halobia-Tosapecten*-bed of the Kochigatani series in Sakawa and the same series at Kuma and Sakuradani regions in the outer zone of southwest Japan. The *kawadai*-bed carries *Sakawairhynchia katayamai* in Hirabara, Sakawa and Sakuradani areas, and dated at Carnic, because *S. katayamai* is closely related to an Alpine *R. arpadica* (1957). *H. aotii* is common in the Nakatsuka formation in Asa, but uncommon in the lower Aso formation* in Mine and absent in Nariwa area. In the upper Nakatsuka formation the *aotii*-bed carries *H.* cfr. *obsoleta* and *Asoella nakatsukensis*. The acmic prominence of *aotii* is probably younger than the *kawadai* bed and older than the *obsoleta*-bed. Thus these five leading species of *Halobia* are arranged in ascending order as follows: *subsedaka*, *kashiwaiensis*, *kawadai*, *aotii* and *obsoleta*. The lowermost is the *subsedaka* bed which lies in the transition between the *Daonella*- and *Halobia*-stages in Japan and indicates the upper Ladinic to lower Carnic age. The uppermost is the *obsoleta* bed, which may lie in the passage between the *Halobia*- and *Asoella*-stages. *Asoella* is widely known in the Carnic and Noric and its acmic prominence lies in the upper Carnic to the lower Noric. It is reported from the *Myoconcha* bed of the Kochigatani series (*Eumorphotis* cfr. *spitzbergensis*) and the upper Nakatsuka formation in Asa beside Aso formation in Mine. The two *Asoella* shales of the Sonose sandstone in the Mine series yield three species of *Rhynchonella*, which are closely related to the Noric species of the Alps (1957). Therefore the middle and upper Aso formation is probably lower Noric, if not uppermost Carnic.

The Noric stage of the Mine series is represented by the *Monotis scutiformis* bed in Asa and *M. ochotica* bed in Nariwa. The former carries *Tosapecten* and small *Halobia*. *Halobia* of the *scutiformis* bed may be a terminal form of the genus, which ranges from Anisic to Noric in the Alps, but has been restricted to the Ladino-Carnic and Carnic beds in Japan. The *scutiformis* bed is said to be Carnic in Siberia (KIPARISOVA, 1954) but it is lower Noric, rather than Carnic in Japan, because rhynchonelloids in the Aso or the subjacent bed of the Kamosho suggest Noric age.

Monotis ochotica is wide spread in the Pacific region in the late Noric age. In Japan, it is reported from several localities of the Saragai formation in Kitakami area, Itsukaichi in Tokyo, Sakuradani, Sakawa and Kuma regions in the outer zone of SW-Japan beside Nariwa and Myogatani areas in the inner zone. The *ochotica* sandstone is remarkably monotonous through these areas.

Finally the Mine series in the three areas are correlated in the figure 12 as follows:

* NAITO in KONNO & NAITO (1960) reported *H. aotii* from the "top of the Momonoki formation", but the horizon belongs to the lowest *Tosapecten* shale of the Mitsusugi sandstone or the lower Aso formation.

Stage	Leading fossils	Mine Series			Kochigatani Series
		MINE	ASA	NARIWA	
NORIC	Monotis ochotica			Jito°	Entomonotis-bed
NORIC	M. scutiformis		Kamosho°	Hinabata	
NORIC	Eumorphotis(Asoella) confertoradiata	Aso°	Yamanoi		
CARNIC	E.(A.)nakatsukensis Halobia aotii H. kawadai H. kashiwaiensis H. subsedaka		Nakatsuka°	Mogami-yama	Myoconcha-bed
CARNIC		Momonoki			Halobia-Tosapecten-bed
CARNIC		Hirabara°	Kajiura	Kyowa°	Oxytoma-Mytilus-bed
CARNIC		Takiguchi	Takago		
		YAMAGUCHI GROUP	MOTOYAMA BRANCH OF SANGUN GROUP		

CORRELATION OF THE MINE SERIES   (°:marine)

Figure 12. Correlation of the Mine series.

2. Tectonic control

The Mine series was deposited in the small intermontane basin controlled by strong crustal movements. In the chapter II the difference between the Hirabara and Momonoki formations in Mine area is discussed in regard to the types of crustal movements. The Hirabara formation is related to strong subsidence of the basin, while the intense and repeated elevations of the hinterland brought about the Momonoki formation. The two types of sediments, i.e. the Hirabara and the Momonoki types are also recognized in Asa and Nariwa areas.

2.1. Sediments which are controlled by subsidence of the basin

The subsidence of the basin is shown by the aspect of the major and minor cycles as well as the textures and properties of cementing matters of psammite and psephite. It is represented by the aspect of minor cycles or graded beds and three major cycles of the Hirabara formation. On the other hand the psephite and psammite of the Hirabara formation belong to the "wacke", containing angular and ill-sorted grains cemented with muddy substances. The "graded beds" and "wackes" appear to be related to the mechanism of "turbidity current" and indicate an unstable basin.

The Nakatsuka formation in Asa area belongs to this type, because it is characterized by "graywackes" and graded beds, although it lacks "slide conglomerates" and major cycles of the Hirabara type.

The Hirabara formation is related to the strong crustal movement which took place in a narrow area. The crustal movement is not so intense in the Nakatsuka as in the Hirabara stage. The sliding conglomerate of the Hirabara formation indicates the intense crustal movement, but it is restricted to the narrow area. On the other hand the graded beds are widely distributed

in the Nakatsuka formation and related to the subsidence of the wide area. Thus the Nakatsuka basin was more stable than the Hirabara basin.

The Jito formation in Nariwa area and the Kamosho formation in Asa area contain wackes and graded beds in some parts, but they are better characterized by the alternation of the Aso type, influenced by the gentle warping of the basin rather than graded beds. Therefore the Kamosho and Jito basins were more stable than the Nakatsuka and Hirabara basins.

2.2. *Shooting sediments from the elevating hinterland*

The Momonoki formation is characterized by the two types of sediments, namely deltaic fanglomerate and coal measure rhythms, composed of thick and coarse arenite and coal seam bearing alternation of muddy sediments. These two are explained by the strong upheaval of the hinterland.

The deltaic fanglomerates are found in the middle Momonoki formation in Mine, the upper Kajiura formation in Asa and the upper Mogamiyama formation in Nariwa. Fanglomerates of the three areas are similar to one another in the constituents and sedimentary structures. They consist of the fore-set and bottom-set beds of the lateral deposits of a delta, although the fore-set bed is uncertain in the Mogamiyama delta.

Coal seams of the bottom-set bed are best developed in the Idenoue-delta or the upper Kajiura formation. Shaly deposits of the lateral facies of the delta are well developed in the Mogamiyama delta, but poorly in the Momonoki delta. Rhythmic sediments of the Momonoki formation are divided into two, the Mugikawa and Omine types or the composite and simple rhythms. The composite rhythms of the Akaiwa alternation or the lower Kajiura formation in Asa area belong to the Mugikawa type. The Yamanoi formation in Asa and Mogamiyama and Hinababa formations in Nariwa area are composed of numerous and fairly monotonous rhythmic sediments of the Omine type. The Mogamiyama formation was deposited in a small lake as the Momonoki formation, but the Yamanoi and Hinabata formations were accumulated in wider basins, seeing that sandstones are abraded in the latter two.

Gentle warpings of the basin are suggested in the shaly members of the Hinabata and Yamanoi rhythms, because the shaly members bear the three parts, each representing transgressive, inundation and regressive stages of an oscillation. The sandstone member of the rhythm is characterized by upward decrease in grain size (from pebbly sandstone to coarse sandstone) in the two Momonoki rhythms and the Mogamiyama rhythm, but massive and almost monotonous in the Yamanoi rhythm. The Hinabata rhythm comprises three types of rocks in the sandstone member; the lower part is arenitic, the middle micaceous and the upper muddy. The micaceous and muddy sandstone suggest slower deposition than the arenites or the Momonoki sandstone, or in other words, they are related to the gentle shooting of sediments. Thus the six rhythmic formations are graded according to the shooting intensity as follows:

1. The *Mugikawa* or the lower Momonoki formation of Mine and *Akaiwa*

rhythms or the lower Kajiura formation of Asa are related to the highly intense shooting.

2. The *Omine, Mogamiyama* and *Yamanoi* rhythms are related to the less intense shooting than the Mugikawa rhythms.

3. The *Hinabata* rhythm is related to the gentle shooting of sediments.

The Aso formation of the Mine series is characterized by massive and monotonous arenite. intercalated by shaly beds, indicating gentle warping of the basin. Since the constituents of the formation are identical to those of the Momonoki formation, there was no change in the provenance between the Momonoki and Aso stages. Therefore the arenites of the Aso formation were also shooting sediments, transported from the axial zone of the Akiyoshiiden.

Therefore the Aso formation belongs to the same type as the Momonoki formation, although shooting intensity is considered smaller than in the rhythmic sediments of the Momonoki type. In the Aso stage the supply or the shooting of sediments kept equilibrium with the subsidence of the basin, and the basin maintained the same depth. The difference between the Momonoki and Aso types may depend upon the crustal movement in the hinterland. The former is related to the repeated and sudden elevations of narrow areas, while the latter may be related to the gentle culmination of a wide area. Coarse arenite of the Kamosho and Jito formations may be also related to the culmination, although the basin was less stable in the Jito and Kamosho stages than in the Aso stage.

3. Tectonic History of the Mine epoch in the three areas

3.1. The lower Carnic stage

The strong and wide geographic relief was formed in the Mine and Asa areas by the movement of the Omine phase. The first deposit in Mine area after the phase was a kind of talus cone around the limestone mass. The subsequent stage was represented by fillings of local depression and uneven surface in the lower Takiguchi stage. Then the basin subsided and received sediments from neighbouring mountains of the Palaeozoic rocks. Finally an embayment was formed in Mine area, in which thick Hirabara cycles were accumulated. The Palaeo-Hirabara bay was open southward. The water was stagnant in the northern half, while it was agitated in the southern half. The three major cycles and characteristic features of sediments in the Hirabara formation are explained by alternating actions of the subsidence of the basin and the fillings of the depression. During the Hirabara age the sea invaded for three times and carries three *Halobia*-shales in the Hirabara formation.

The contemporaries of the Takiguchi and Hirabara formations in Asa area are represented by the Takago and Kajiura formations. The Takago conglomerate is similar to the basal Takiguchi and Hirabara conglomerates in the constituent, texture and mode of occurrence. It suggests strong and steep relieves around a local depression. Such steep topographic relieves as recorded in the conglomerate were probably produced by the Omine phase of orogeny,

although the precise correlation is not yet established, because no marine fossil is collected in the Takago and Kajiura formations. The subsequent stage is represented by the Kajiura rhythm and deltaic conglomerate, in which repeated and sudden elevations of hinterland or the axial zone of the Akiyoshi folded mountains are recorded. The Kajiura formation was accumulated in a small lake in the folded mountains, and the sediments were transported from the west.

It is noticeable that the strong subsidence took place in the Mine area in the lower Carnic stage, at the same time with the intense upheaval in the axial zone of the Akiyoshiiden. It is interesting that almost no effect of the elevation in the axial zone is recorded in the Hirabara formation. The Hirabara basin did not receive the sediments from the axial zone of the Akiyoshiid, where granitic, volcanic as well as schistose rocks were exposed, but only received them from the surrounding areas of the basin, where the nonmetamorphosed Palaeozoic Yamaguchi group was exposed. A few red zircons and amphiboles are found as the accessory minerals in the sandstone in the southern Hirabara basin. They are dominant in the Kajiura sandstone and reveal their derivation from andesitic and metamorphosed rocks of the axial zone. Therefore it is evident that there was a small amount of supply of sediments from the axial zone to the southern Hirabara bay, where water was agitated, although they were transported secondarily by current from the open-sea.

At all events such intense crustal movements as indicated by the Hirabara and Kajiura formations seem to influence only narrow areas.

At a certain time of the late Hirabara age, there was an embayment in Kyowa area, where the crustal movement was gentle, because the Kyowa formation is thin and characterized by fairly monotonous muddy sediments.

3.2. The middle Carnic stage

Through the Momonoki phase of orogeny the Palaeo-Hirabara bay became the Palaeo-Momonoki lake, in which voluminous and coarse fluvial sediments were accumulated. The lake was about 10 km in diameter, situated in the folded mountains in the northwest of the basin. The Momonoki formation comprises two coal measure rhythms and a deltaic fanglomerate between the two. They are similar to those of the Kajiura formation of Asa area, in constituents and sedimentary structure. It is presumable that the sudden and repeated elevatious of the axial zone were responsible for the two kinds of sediments in the Momonoki formation as in the Kajiura formation.

At the same time there was also a lake in Nariwa area, where Mogamiyama rhythms were accumulated. The basin was wider than the Momonoki lake and the sediments were transported from the north. At a certain Momonoki age, sea invaded into Asa area, and the sediment at the time is represented by the Halobia-shale of the lower Nakatsuka formation. This formation is a neritic sediment in the subsiding basin, although the subsidence was not so intense as the Hirabara stage. The Nakatsuka basin received the sedi-

ments from the surrounding region of the non-metamorphosed Yamaguchi ter-
rain as well as the metamorphosed axis of the folded mountains.

3.3.   The upper Carnic stage

The hinterland of Mine area was elevated less intensely in the upper
Carnic than the Momonoki stage as represented by oscillatory sediments of
the Aso formation. They indicate gentle warping of the basin, although shoot-
ing of sediments from the axial zone lasted until the Aso age. The relief of
the hinterland at the time was milder but wider than in the Momonoki age.

The elevation of the hinterland was, however, intense in Nariwa area, be-
cause the rhythmic sediments of the Mogamiyama and Hinabata formation
included the upper Carnic sediments.

In Asa area fluvial shootings became suddenly intense in a certain Aso
age, and the rhythmic sediments of the Yamanoi formation were accumulated.
The elevation of the hinterland is recorded in the Momonoki type rhythm in
the nearshore sediment, and in the rhythms of clean and carbonaceous sand-
stones in the off-shore part of the Yamanoi basin.

3.4.   The lower Noric stage

The lower Noric is represented by the massive Sonose sandstone in Mine
area, which represents the constant supply of sandstone from the axial zone
of the folded mountains and gentle and occasional warpings of the basin.

The Yamanoi formation in Asa area includes the lowest Noric stage, which
is somewhat massive as the Mitsusugi sandstone. It is followed by the trans-
gression of the *scutiformis*-bed of the Kamosho formation. The Kamosho for-
mation represents the gentle downwarping of the basin.

The lower Noric of Nariwa area is represented by the Hinabata rhythm. It
is similar to the Yamanoi rhythm, but represents a condition of slower deposi-
tion than the Yamanoi sediments.

3.5.   The middle and upper Noric stages

The only representative of the late Noric in the Mine series is the Jito
formation in Nariwa, which is represented by the transgression of the *ochotica*-
bed. Since the bed is characterized by the monotonous and coarse sandstone
through its distribution in Kitakami, Kwanto, Kinki, Shikoku and Kyushu, it
is considered that it was deposited on the wide and open shelf. It is evident
that the intense orogenic movement was ceased and the mountains were con-
solidated before the stage. The wide submergence of the *ochotica*-bed was
followed by the wide emergence of the Rhaetic Toyogatake phase, by which
the Akiyoshi folded mountains were completed.

PART II
NOTE ON THE OTHER OROGENIC SEDIMENTS
OF THE AKIYOSHI CYCLE

I. Pre-Orogenic Stage

The history of the Alpine type folded mountains begins with the birth of the geosyncline. It represents the initial stage of the orogeny and includes the pre-history of the folded mountains. One can understand under the term " geosyncline " a strongly mobile and especially subsiding belt of the earth. It is characterized by the thick accumulation of clastic sediments as well as submarine volcanisms.

The Chichibu geosyncline dates back before the Silurian (Gotlandian) age (HAMADA, 1959). It has been differentiated into the inner and outer sides as early as Devonian. Since then it has been developed as two geosynclines until Upper Palaeozoic. They have similar facies arrangement in the Carbonaceous and Permian (KIMURA, 1957, 1960), although the northern wing of the geosynclines has not been yet clearly restored. There is a belt of the submarine volcanism or so-called " Schalstein " in the axial zone, which is most extensive in the Upper Carboniferous. In the southern wing of the two geosynclines three facies are enumerated. They are arranged from north to south as follows :

1) The first facies is characterized by chert and siliceous shales, relatively massive. It is represented by the Gampi series in the inner zone and the Ogawago facies in the outer zone. According to KIMURA the " Wurzel " of the Akiyoshi-Decke, which is represented by monotonous limestone, may have been situated to the north of the Gampi zone.

2) The second facies is characterized by dominant graded beds. It is represented by the Tsunemori series in the inner and the Ichinose facies in the outer zone. They are characterized by graywackes and graded beds beside subordinate Schalsteins and cherts and reveal a fairly steep slope of the bottom between the northern and southern parts.

3) The third facies is characterized by monotonous sandstones. It is represented by the Ota series in the inner and Nomisaka facies in the outer zone.

The similar facies arrangement is also found in the northern Kitakami mountains in northeast Japan.

Little has been known as to the northern wing or the continental side of the geosyncline, because this terrain was turned out later into a gneissose rocks of the Hida or Ryoke types in the inner or outer zone respectively. Accordingly outcrops of the unmetamorphosed rocks are extremely restricted in these terrains. They are, however, well represented by the strata of the western part of the southern Kitakami region. Sediments of this region reveal a relatively stable basement. For instance, there is a continuous lime-

stone from the *Pseudoschwagerina*-zone to the *Neoschwagerina*-zone. It is re-markable that the basin maintained a fairly constant condition, under which the monotonous limestone could be precipitated. The limestone is inserted sometimes by coarse and crinoid-bearing limestones, and sometimes by ex-tremely fine and pure limestones of chemical deposits. A layer of fusulinid limestone lies between the two limestones. The successive change of the lime-stone facies suggests the gentle warping or oscillatory movements of the stable ·shelf.

Another representative of the northern wing of the geosyncline is found in the Ichinotani area in the Hida region (IGO, 1960), where the kaolinite-bearing red beds alternate with flintly layers, suggesting "palaeosoil", beside sandstones of orthoquartzite series, showing wide and stable shelf, in the Middle Carboniferous to the Middle Permian. The rhythmic bed of the kao-linite and flinty layers indicate also the gentle warping of the stable mass. The tectonic movement of the Ichinotani area is similar to those in the south-ern Kitakami facies.

As for the non-metamorphosed Palaeozoic rocks of the Ryoke terrain in the inner zone, no sufficient data has been published to discuss in detail.

II. Prorogenic Stage

1. Late Permian development

In the Chichibu geosyncline, the basic submarine volcanism was declined before late Permian. The late Permian is characterized by absence of "Schal-stein", including basic pyroclastics and lavas, and by dominant black muddy facies. It includes two characteristics facies, namely the Kuma and Toyoma series, beside Usuginu and Yasuba types of conglomerate.

1.1. Kuma series

The Kuma series (KANMERA, 1953) represents the last stage of the Chi-chibu geosyncline. It is about 900 m thick and distributed in Kuma area in central Kyushu (KANMERA, 1953), Sakuradani area (=Haigyu group by ICHI-KAWA, YAMASHITA et al., 1957) and in Maizuru area in Kinki (=Maizuru group by NAKAZAWA, SHIKI, SHIMIZU and NOGAMI, 1958). It is on the whole made up of black shale, sandstone and conglomerate with small lenses of dark and impure limestone, and characterized by frequent facies change. The conglo-merates are embedded in muddy rocks, composed of rounded and exotic peb-bles of granitic, dioritic as well as gabbroic rocks, angular and small fragments of shale and sandstone, which were probably reworked from the surrounding Palaeozoic rocks, and cemented with muddy as well as graywacke matrix. They often wedge in black muds and reveal aspects of "slide conglomerate" (fig. 13). Limestones are often sandy or muddy and impure, embedded as small lenses; they include sometimes angular fragments of Palaeozoic rocks, and bear " *Yabeina-Lepidolina*-fauna ", *Neoschwagerina douvillei*, *Yabeina globosa* for example. Cherts and "Schalsteins" which are abundant in the subjacent beds

are absent in the Kuma series.

In the typical section near Tsuru, 8 km to the east of Yatsushiro, the lower third (about 300 m thick) is occupied with black shales, fairly well stratified and provided with sandy intercalations. The sandstone is fairly well sorted and stratified.

The middle member, about 450 m, is characterized by graywackes and frequent insertions of conglomerate. A conglomerate layer is thicker than 10 m. It is sometimes a wedge in shale and sometimes embedded in graywacke. Rounded and angular pebbles are ill-sorted and irregularly arranged. They are sometimes closely packed, but sometimes sporadical. Most of round pebbles are igneous rocks, for example, granite, diorite, quartz-porphyry and diabase. Sand and shaly pebbles are angular and smaller than igneous rocks. Fragments of limestone and shale are reworked pebbles and irregularly shaped. The matrix is commonly fine and consists of lithic and graywacke, cemented with black and bituminous muds. It is extremely ill-sorted and sometimes as coarse as breccia (fig. 13).
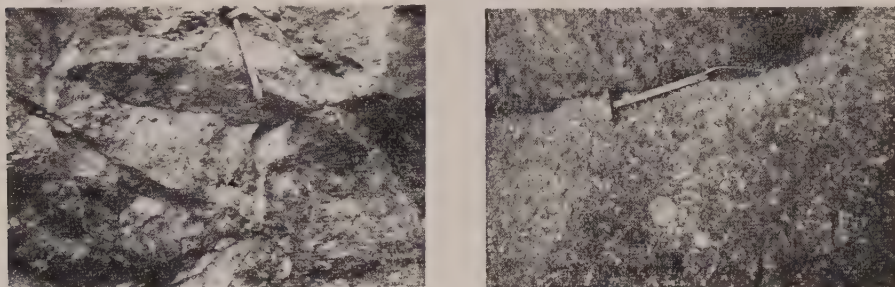

Figure 13. "Slide-conglomerate" of the Kuma series in Maizuru area,
East of Gujo, Hyogo Pref.

The sandstone of the member is a kind of microbreccia, composed of angular and ill-sorted fragments of shale and chert beside quartz and feldspar; it is cemented with black and muddy matrix (Pl. XVIII figs. 1-4). It is a remarkable fact that the sandstone contains fragments of quartz-schist, although the amount is small. Plagioclase exceeds sometimes 5%; sometimes hornblende is crowded. The matrix is occupied by black shale, somewhat bituminous.

The sediments of the middle member are characterized on the whole by "bottom sliding". The upper part, about 200 m thick, is composed of alternating beds of sandstone, shale and mudstone, inserted by conglomerate layers. Sometimes it is characterized by graded beds. The sandstones in the graded beds are, as shown in figure 4 on Pl. XVIII, characterized by graywackes, which are extremely ill-sorted, and grains irregularly arranged.

There is a considerable change in rock facies. Sometimes conglomerates are dominant in the lower part, and sometimes graded beds predominate over the muddy sediments.

In *Sakuradani area* it is distributed as two patches in Kito and Haigyu areas, in the Chichibu terrain. It is about 300 m thick and composed of sand-

stone and mudstone, intercalated by conglomerate layers and contains rounded pebbles of porphyrite and diabase beside angular and irregularly shaped sandstone and shaly boulders. The lower part is somewhat massive, while the upper part is composed of graded beds. The lithology and fusulinids of the beds are similar to those of the Kuma series.

In *Maizuru area* the Kuma series crops out in several localities in Yakuno and Maizuru areas and called Maizuru group (NAKAZAWA, SHIKI, SHIMIZU and NOGAMI, 1958). It is thicker than 600 m, composed of alternating beds of mudstone, sandstone and conglomerate and characterized by frequent facies change and slide conglomerate. It contains fossils in the two facies, namely in impure limestone and mudstone. The limestone contains fusulinids of the Kuma fauna (NOGAMI, 1958), while the shale contains many brachiopods and pelecypods such as Bakevelliids, Myophoriids and Aviculopectinids (NAKAZAWA, 1959, 60).

1.2. Rock facies of the Kuma series

The Kuma series is characterized by black muddy sediments and intercalations of slide conglomerates and impure limestones. It bears neither schalstein nor chert through the three area.

The conglomerate of the Kuma series is characterized by rounded pebbles of igneous rocks and angular and irregularly shaped shaly as well as sandy rocks. They are ill-sorted and irregularly arranged and embedded in muddy rocks. They form sometimes wedges and sometimes small lenses in muddy beds. Therefore the conglomerates must have been suddenly supplied in the muddy basin. Such mechanism is best explained by the bottom sliding or the like (KUENEN, 1960, KUENEN & CARROZZI, 1953). The textures and angular fragments of rocks indicate the bottom sliding. Similar texture is found in the graywackes of the graded beds, which are considered to be produced by "turbidity currents". The bottom sliding may take place when the basin is unstable or the basin is steeply inclined by sudden local subsidence.

MATSUMOTO & KANMERA (1949) and NAKAZAWA (1959) considered the conglomerates to be deltaic fanglomerate, produced by fluvial shooting. However, the mechanism is not satisfactory for the Kuma conglomerate. As already mentioned, the slide conglomerate is quite distinctive from the fluvial conglomerate in various points especially in textures and mode of occurrence. The matrix of the Kuma conglomerate is probably produced by sliding instead of fluvial shooting. Then, what does the rounded pebbles of the Kuma conglomerate mean? It is evident that the rounded pebbles of the igneous rocks were exotic to the Kuma series, because there is no igneous body near the basin. The rounded pebbles must have been transported by fluvial current. However, the matrix of the conglomerate suggests the bottom sliding. Therefore it is presumable that the pebbles were reworked from the conglomerate of the surrounding area, which had been transported from some distant areas. There are conglomerates of Usuginu-type, bearing rounded pebbles of igneous rocks, in several localities in the Permian of the Chichibu zone in Shikoku. If the exotic boulders of the Kuma conglomerate are ex-

plained as the reworked pebbles from the Usuginu conglomerate, they are easily explained by the mechanism other than the "fluvial shooting" in the Kuma basin. The Usuginu conglomerate is considered to depend upon the geanticlinal upheaval, taken place in the outside of the Chichibu geosyncline.

Characteristic features of the Kuma series such as slide conglomerates, (KOBAYASHI, 1941), graded beds, muddy sediments and absence of "Schalstein", recall one of the Cretaceous and early Tertiary Flysch of the Alps (ALLEMANN, 1957, KRAUS, 1932, 41, 57, NÄNNY, 1948) as well as the early Carboniferous Kulm graywacke (FIEGE, 1937, MATTIAT, 1960). In the Alpine Flysch, slidings of a large or small scale were repeated on the sea floor. The exotic pebbles were transported from the "fore-head" swells (Stirnschwelle) of the Decke or the "vorwandernde Decke", which were considered to have been hidden by the thrusting of later stages of the orogeny (KRAUS, 1932, 57). Therefore the Kuma series must be a kind of Flysch, as already noted (1960b), instead of Molasse as MATSUMOTO & KANMERA (1949) and others have considered.

It is true that the sliding conglomerates are found also in the Molasse as in the Hirabara formation of the Mine series, as well as in the postorogenic sediments such as in the Lower Jurassic Kuruma series (post-orogenic of the Akiyoshi cycle) and Upper Cretaceous Onogawa-Izumi series (post-orogenic of the Sakawa cycle), but they are easily distinguishable from those in the Flysch, because the slide conglomerates of the post-orogenic stages (s. l.) contain many terrigenous matters and they were accumulated in the embayment or inland sea, while those of the Flysch is characterized by paucity of terrigenous matters and they were deposited in the open sea, because they represent the latest stage of the geosyncline.

Through the crustal movement of the Kuma epoch, the geosyncline was differentiated into flysch basins. There is another characteristic Flysch in the Kitakami region, called the Toyama series.

1.3. Toyoma series

The Toyama series in the Kitakami mountainland is 1500 to 2000 m thick and composed of monotonous and compact black slate, with subordinate sandstone layers in the middle part. It is somewhat bituminous and almost barren of fossils except for trails of *Notaculites* and a few brachiopods in the lower part of the series. The mother rock of the trail is a fine sandy shale, and the trail filled up by black muddy substance. The rock consists of quartz and carbonaceous matter containing minute grains of primary pyrite, marcasite or some other iron sulphides (KOBAYASHI, 1954). They suggest bituminous and somewhat stagnant water, although the lamina reveals weak current. Seeing that the delicate trails are preserved undamaged, the basin must have been tranquil. Therefore the basin was presumably embraced by an 'unknown submarine ridge' (KOBAYASHI, 1945). Because the rock is bituminous and almost barren of fossils, sea bottom at the time was probably not suitable for the common benthos and nectons.

The thick and monotonous Toyoma slate reveals that the basin maintained

such a stagnant condition for a long time, during which the subsidence of the basin and supply of sediments were balanced. Considering the fact that the contemporaneous Kuma series, which contains many conglomerate layers and graded beds is 900 m thick, the Toyoma basin was fairly rapidly subsided.

It is well known in the Alps that the change of the bottom relief restricted the basin to make a partial stagnant flysch basin, where no normal benthos or nectons could live except "Fukoid"-marking organism, and monotonous and muddy sediments were accumulated in the Flysch stage (KRAUS, 1957; SEILACHER, 1960). There were several partial basins (Teilsenke) in the Allgäu-Flysch, which were differentiated from the geosyncline by the crustal movement of the "Stammfaltungen".

The late Permian crustal movements of Japan are similar to the Stammfaltungen, because there were two distinct flysch facies, namely the Kuma series, containing slide conglomerate with exotic boulders, like "Wildflysch", in the southern part of Japan and the monotonous slate of the Toyoma series in the Kitakami area in north Japan. According to SADA (1960) the Terauchi formation of Atetsu region in Bitchu includes late Permian. It is as thick as 750 m and characterized by monotonous shales and sandstone with small limestone lenses and thin chert layers in the lower part. This may represent the third facies of the flysch.

2. Skyto-Anisic development

2.1. The Inai series in Kitakami area
General geology

The Inai series, widely distributed in the southern Kitakami region, lies on the Upper Permian Toyoma series with disconformity and is overlain by the Noric Saragai series and Liassic Shizukawa series unconformably. It is 1500–3000 m thick and made up of the following four formations:

4.	Inai sandy slate	1000–2550 m thick
3.	Kazakoshi sandstone and conglomerate	50– 600
2.	Osawa dark blue slate	180– 350
1.	Hiraiso sandstone and conglomerate	80– 300

The Hiraiso sandstone is composed of two parts. The lower part, as thick as 60 m, is conglomeratic, and the upper or the main part is composed of alternating beds of calcareous shale, calcareous sandstone and sandy slate. The basal conglomerate contains subround pebbles, which are smaller than 60 cm in diameter, containing granitic rocks, porphyrites, cherts, shales and limestones. The alternating beds are sometimes laminated and show water current. Calcareous shales in the lower part contain *Eumorphotis*, pectinids and other pelecypods, which indicate Skytic age.

The Hiraiso sandstone belongs to the quartz sandstone. It consists of round quartz, subordinate feldspar and subangular rock fragments of cherts, which are scattered in the calcareous cement. The grains are well abraded and represent a high maturity. They are floats in the original carbonate

cement (Pl. XVIII, fig. 5).   The primary precipitation of carbonate is supported by dominance of calcareous shales and fossiliferous limestone of the formation.

The Osawa dark blue slate, 180–350 m thick, is composed mainly of the calcareous and blue banded slate, sometimes intercalated by thin sandy layers. Ammonites and pelecypods in the dark blue slate of the upper part are Skytic in age.

The Kazakoshi (or Fukkoshi) sandstone, commonly about 200 m thick, is a sandy intercalation in the Osawa and Inai slate formations and characterized by pure quartz-sandstone, but grains are not so well rounded as in the Hiraiso sandstone.   It contains angular feldspar grains and sometimes mica flakes, as well as shaly patches.   It carries small brachiopods in rare instances, indicating Anisic age.

The Inai sandy slate, attaining 2500 m in thickness is mainly composed of banded slate, with some sandy layers.   The banded slate is made up of alternations, consisting of calcareous and impure dark sediments.   The alternation is composed of the two layers of different qualities, instead of being marked by grain-size change.   More precisely, the grain size of particles are nearly equal through the beds, while the matrix changes periodically.   The quartz and feldspar grains were accumulated in the constant rate of sedimentation. The matrix is occupied by calcareous precipitates in one bed, while impure and dark substances are predominant in another.   The matrix-change depends probably upon the abrupt change of electrolite in the basin, because the calcareous cement of the rock is considered to have been produced by colloid or chemical sedimentation.

When the colloid or electrolites of different sign are introduced in the basin, there will be abrupt change in deposition.   If the carbonaceous matters or electrolites of different sign are abruptly introduced in the basin, where calcareous sediments have been deposited, the muddy sediments, which have been suspending in water, may be deposited together with carbonaceous matters in the place of carbonate sediments.

Numerous small mica flakes are often gregarious in thin layers, which are intercalated in the monotonous calcareous slate.   *Hollandites*, *Danubites* and other ammonites determine the Anisic age of the Inai slate.   The thickness of the formation varies from 1000 m at Yatsu to 2500 m at Isatomae.   This is explained by the strong local subsidence of the basin.

Condition of sedimentation

In comparison with the two flysch sediments, the Toyoma slate is bituminous and almost barren of fossils except trails of *Notaculites*.   It was deposited in stagnant water, but the Inai slate contains fairly numerous neritic shells. The Hiraiso sandstone (Pl. XVIII, fig. 5) is characterized by well rounded quartz, and subordinate feldspars and fragments of cherts, which are embedded originally in carbonate cement.   The roundness and high maturity reveal the water current, while the fine chemical or colloidal precipitates of matrix show the tranquil water of the basin.   It is evident that the grains had been

abraded and sorted for a long time before they reached the basin. If the water was tranquil in the basin, the water current around the basin may not have been very strong. If so, such high maturity and roundness as in the Hiraiso sandstone are rather peculiar. It is presumable that most of quartz and feldspar were reworked from Palaeozoic sandstones. Seeing that the terrigenous matters are insignificant in the Inai series, there were yet weak and small topographic relieves in the epoch.

Since the Inai slate are fairly monotonous in lithology, the rate of deposition and subsidence of the basin were balanced. The frequent local change of its thickness represents the local difference in subsidence of the basin. The monotonous and calcareous sediments of the Inai series resemble those of the Alpine flysch in lithology and aspect of banded slate.

2.2. *Yakuno series in Yakuno area*

Contemporaries of the Inai series are found in several areas of the Maizuru region. They are distributed in Fukumoto, Yakuno, Kawahigashi and Kawanishi areas and called as the Yakuno series (NAKAZAWA, 1959). Because they are intensely disturbed, the biostratigraphic works are yet incomplete. In this paper I shall discuss only the Yakuno series in Yakuno area from my own observation.

The Yakuno series overlies the Palaeozoic rocks disconformably and about 850 m thick in Yakuno area, where it is divisible into two formations, namely the lower Honodani and upper Waruishi formations (NAKAZAWA, SHIKI & SHIMIZU, 1957).

The Honodani formation, 400–500 m thick, is composed of mudstones graywackes and graded beds. The mudstone and graywackes are simultaneous to those in Permian Maizuru or the Kuma series, although there is no remarkable slide conclomerate in the Yakuno series. It yields Myophoriids (NAKAZAWA, 1960) and *Eumorphotis* and belongs to the Skytic stage.

The Waruishi formation, 300–400 m thick, is made up of dark green banded slate of the Inai type, beside sandstone and conglomerate. It is noticeable that the muddy slate of the upper Honodani formation merges upward into dark green banded slate of the Inai type. Incidentally the graywackes of the Honodain merge into quartz sandstones in the Waruishi formation.

The Waruishi sandstone contains rock fragments as well as feldspars and quartz which are subangular and relatively ill-sorted. They are, however, embedded in calcareousm atrix as Hiraiso sandstone. The Waruishi sandstone is lower in maturity than the Hiraiso, because it contains more numerous unstable fragments (Pl. XVIII, fig. 5) than the Hiraiso sandstone (Pl. XVIII, fig. 8). The calcareous matrix shows the Waruishi sandstone to be deposited under a similar condition as the Hiraiso one.

A thick conglomerate crops out in the northwestern part. It contains rounded pebbles of chert and granitic rocks as well as shales and sandstones. The pebbles occur rather sporadically in the sandstone of Waruishi type. It is similar to the Hiraiso conglomerate in constituents and textures, although

pebbles are coarser and more closely packed than the Hiraiso one. Therefore the conglomerate belongs to the Waruishi formation rather than to the Hono-dani formation.

The Waruishi formation yields " *Danubites* " and *Hollandites* beside brachio-pods and small pelecypods. They indicate the Waruishi formation to be lower Anisic or coeval to the Kazakoshi and lower Inai formations of the Inai series, although the assemblage of the Waruishi fauna is not identical to the Kaza-koshi and Inai faunas.

Condition of sedimentation

It is an important fact that the Honodani formation or the lower Yakuno series is represented by a kind of geosynclinal facies as the subjacent beds, while the Waruishi formation is represented by the Inai facies. The Honodani facies is not typical for the geosyncline, because the muddy facies is predominant and the graded beds are neither regular nor well developed as in the subjacent Palaeozoic formation. On the other hand the Waruishi sandstone does not belong to the pure quartz-sandstone as the Hiraiso sandstone, because it contains plagioclases as well as fragments of shales (Pl. XVIII, fig. 8). It is so-to-speak an intermediate rock between the graywacke and pure quartz sand-stone. The lithologic change of sandstone and shale between the two forma-tions is gradual in Yakuno area. The shale of the lower Waruishi formation is somewhat muddy as in the Honodani formation, but it passes upward into banded slate and pure calcareous precipitates as in the Inai formation.

In the Kitakami region the Inai flysch basin took place of the Toyoma basin in the lower Skytic, which the latter represents a kind of flysch basin and was differentiated from the geosyncline in the late Permian in the Usuginu phase. On the other hand, in Maizuru region, the Kuma series, which repre-sents the last stage of the geosyncline has differentiated into the Yakuno flysch of the Inai type in the Skyto-Anisic age. The Flysch basin of the Inai type appeared earlier in the Kitakami than in the Maizuru region. Because most of the Lower and Middle Triassic sediments have been denudaded in other regions of Japan, little is known of the later development of the flysch sediments. It is a question, whether any other flysch basin has existed or when the flysch sediments have disappear.

The Aniso-Ladinic Rifu formation near Sendai may belong to a kind of flysch, because it is similar to the Inai slate in lithology. The Ladinic Zohoin series may represent a geosynclinal stage of the Sakawa orogeny, rather than the flysch of the Akiyoshi orogeny.

The subsequent stage of the Inai facies in the Akiyoshi cycle is therefore represented by the upper Ladnic Zuiko formation of the Atsu series.

III. Eu- and Meta-Orogenic Stages

The eu- and meta-orogenic stages of the Akiyoshi orogeny are represented by the Atsu and Mine series in West Japan. The crustal instability of the

stages is explained in this paper by phase and facies analyses of the two series. The folded mountains were completed through these crustal movements. The large ragged mountains were built suddenly in the late Atsu epoch. The Mine series is a synorogenic sediments, containing a large amount of coarse terrigenous matter. It is extraordinal that sediments of the Atsu and Mine series were accumulated over 8000 m in thickness in a short time from late Ladinic to early Noric. The Mine series is similar to the Alpine Molasse not only in lithology in aspects of fluvial deposits and rhythmic sediments but also in the stratigraphic relation to the flysch and postorgenic sediments. Since Mine basin was formed in the intermontane zones, the crustal movements in the mountains were recorded in detail in the Mine series. On the other hand the Alpine Molasse was accumulated in the fore-deep of the Alps. Therefore the Molasse basin is more distant from the provenance than the Mine basin. In this sense the Mine series shows a better example of the meta-orogenic sediments than the Alpine Molasse.

In the Alps the Molasse stage is characterized by thrusting and foldings of the mountains. The meta-orogenic stage is considered to be the stage of mountain-building and therefore it represents the most intense crustal movement in the orogenic cycle. In other words it is the "hochorogenes Stadium".

IV. The Post-Orogenic Stage

The post-orogenic stage is represented by the three types of sediments. They are the Noric Saragai, Noric (?) Shidaka and Liassic Kuruma series. *The Saragai series* is neritic and distributed widely around the Akiyoshi folded mountains. It is a product of the Noric transgression, which is marked by *Monotis ochotica* and flooded on the foot of the mountains. It is characterized by coarse and monotonous sandstones through its distribution. *The Shidaka series* is an intermontane basin-deposit and represents a more stable state of the crust than the Mine epoch. *The Kuruma series* is a very thick and massive sediment of an embayment along the axis of the folded mountains.

1. Saragai series

The Saragai series lies on the Inai series with disconformity in Kitakami area. It is as thick as 250 m and divided into three members in Saragai area (Ichikawa, 1951).

The lower member, 20–140 m thick, is composed of grey "arkose" sandstone, containing thin beds of shale or banded slate. Sometimes they are laminated, probably by water current, and are fairly carbonaceous in part.

The middle member, 30–70 m thick, consists of coarse sandstone, somewhat micaceous, with black shales and grey mudstone, containing fragments of plant fossils. It is somewhat more muddy than the lower member.

The upper member 80–120 m thick, is composed of alternating beds of coarse sandstone and shales, sometimes micaceous. It contains numerous shells of *Monotis* (*Entomonotis*), by which the member is zonated into 5 fossil zones

(ICHIKAWA, 1958).

The Saragai sandstone belongs to the same group as the Momonoki-Aso sandstone. It consists of fragments of andesite, quartz and feldspars as well as shaly fragments. Quartz and feldspar were derived from the same granitic rocks as were exposed in the Mine epoch, because the microcline, albite and orthoclase bear similar properties to those of the Momonoki sandstones. The Saragai sandstone carries sometimes muddy matrices as the Hinabata sandstone in Nariwa area, and sometimes carries clastic matrices as the Aso and Jito sandstones. Sometimes it is calcareous. It is evident that the sandstone was accumulated on an open shelf, because fragments are abraded and filled with clastic matrices, or in other words, they were agitated. At all events the Saragai sandstone represents more stable condition than the Mine epoch.

If the Saragai series is characterized by *Monotis ochotica* and the coarse sandstone, it is extensive in Japan. The similar sediments are found in Itsukaichi near Tokyo, Sakuradani and Sakawa in Shikoku, Kuma in Kyushu and Myogatani near Ibuki, beside Jito formation in Nariwa area, although they are sometimes conglomeratic as in Myogatani and Otogo in Sakawa. The Saragai sandstone is distributed in all of the four terrains being independent to the tectonic zones, namely in (1) the inner zone, (2) inner periorogenic zone and (3) outer periorogenic zone of the Kochigatani facies as well as (4) Kitakami region. Through these areas the *Monotis*-sandstone is uniform in constituents and textures, although it is sometimes muddy, calcareous or pure sand rock.

It is important that such a monotonous sandstone was extensive at that time. The Saragai sandstone indicates a fairly stable shelf. It is evident that the shelf was widely developed around the Akiyoshi folded mountains in the late Noric, because it carries always *M. ochotica*. Therefore the late Noric transgression was responsible for the wide shelf. *M. ochotica* is distributed not only in Japan, but also in the Pacific regions such as in Ussuri and Alaska in the northern Pacific and in New Zealand and New Caledonia in the southern Pacific. On the other hand such uniform constituents of the Saragai sandstone depend largely upon the provenance. The Akiyoshi folded mountains are considered to have been completed by the Saragai epoch and most parts were consolidated as early as the Saragai age.

2. *Shidaka series*

It is a coarse and thick sediment, distributed in the Maizuru region. It comprises the Shidaka series (s. s.) and Miharaiyama formation (KAMBE, 1957). KAMBE (in KOBAYASHI, 1948) was the first in Japan who carried out the grain size analysis of the shooting sediments among the orogenic sediments. He recognized five shooting phases in the Shidaka series.

2.1. *General geology*

According to KAMBE (1950), the Shidaka series is as thick as 1700 m, consisting of five members (MI-MV). It lies on the upper Palaeozoic rocks with

clino-unconformity. The basal member (MI) about 180 m thick is composed of conglomerates and thin layers of shales. It contains numerous cherts but lacks igneous rocks. The two middle Shidaka formations (MII, MIII) are characterized by several layers of coarse conglomerates. They are variegated, containing red, green and white cherts, fusulinid limestone, sandstone, granitic rocks and porphyrites. The pebbles are well rounded and attain 50 cm in diameter (lowest layer of MIII). Shales and sandstones become predominant in the MIV and MV formations. The MV formation contains this coal and thick sandy layers, containing Myophoriids (Kambe, 1951), near the top horizon.

2.2. Condition of sedimentation

The Shidaka sandstone is composed of similar constituents as the Momonoki-Aso sandstone in the Mine series, although it contains more numerous chert fragments than the Momonoki sandstone. It is characterized by numerous mica flakes and rounded particles. In this point it resembles the Hinabata sandstone in Nariwa area but it is better abraded, sorted and containing more numerous mica flakes than the Hinabata sandstone. It is sometimes muddy in the upper two formations (MI, V) as in the Hinakata formation.

Shales of the MIV and MV formations are dark green and resemble shaly intercalations of the Hinabata formation in grain size and aspects, although the shaly intercalation of the Hinabata formation is black. The dark green colour of the Shidaka shale depends upon the detritus of andesite, as in the clastic matrix in the Aso sandstone.

The muddy sandstone and other muddy rocks in the Shidaka series are similar to those in the Hinabata formation in Nariwa and represent slow depositions in the stable basin; the micaceous sandstone suggests a long suspension in water before settlement. The conglomenates of the Shidaka series are bearing neither characteristic features of delta and alluvial fan, nor rhythms as the Momonoki ones of the Mine series. Therefore they do not depend upon the periodic and intense oronization as in the Mine epoch. It is presumable that the gentle upheaval or the emergerence of the wide hinterland was responsible for the Shidaka conglomerate, because they reveal slower deposition than the Mine series.

2.3. Shidaka series in Miharaiyama area

The Shidaka series in Miharaiyama area was discovered by Kambe in 1950. It is about 500 m thick, lies on the Palaeozoic rocks with clino-unconformity and composed of conglomerate, sandstone and mudstone. It contains Myophoriids, common to those from Shidaka area (Kambe, 1957).

The conglomerate of the middle part contains black, white and green cherts and subordinate sandstone and shale, attaining 8 cm in diameter. Pebbles were supplied in the basin, where mudstone was accumulated. Therefore they reveal weaker shooting and slower deposition than the Mine conglomerate, which represents a shooting phase and carries no muddy matrices.

Most of the Miharaiyama sandstone bear muddy matrices as in the upper Shidaka and Hinabata formations.

The bituminous and muddy matrices of the sandstone are seen in the late Hinabata stage and Shidaka series, though uncommon. They are however, very common in the sandstones of the Liassic Kuruma series. No conglomerate with the mudstone matrix is found in any shooting conglomerates of the Mine series. It is also absent in the Shidaka series, but common in the Kuruma series, which is a post-orogenic basin-deposit.

Thus the Miharaiyama formation represents probably a subsequent stage of the Shidaka series.

2.4. Note on the age of the Shidaka series

The Shidaka series was once considered to be Jurassic on the basis of the "Shidaka flora" (YABE, 1922, OISHI, 1932, KOBAYASHI, 1938). However, the discovery of myophoriids near the top of the Shidaka series (KAMBE, 1950, 53) dated its age to be Triassic. He considered it as late Triassic, because it yields plant fossils of Jurassic aspects. Subsequently he discovered similar myophoriids from the Miharaiyama formation and correlated the Myophoria-faunule to the Shidaka fauna.

As the result of bakeveliid and myophoriid studies, NAKAZAWA (1958, 59, 60) concluded the Shidaka series to be Skytic. He considered that the Shidaka and Miharaiyama represent coarse grained or near-shore equivalent of the Skyto-Anisic Yakuno series. There is however, no sharp index fossil indicating the Lower and Middle Triassic among the bakevellid and myophoriid species of the Shidaka and Miharaiyama fauna. Therefore his conclusion is intenable.

From the view-point of the tectonic history, the Shidaka series is a post-orogenic sediment, representing the later stage than the Mine series, because the crusts are considered to have been more stable in the Shidaka than in the Mine epoch. The conglomerate and sandstone of the Shidaka series reveal intermediate characters between the Liassic Kuruma and the Carno-Noric Hinabata formation, i.e. the upper Mine series. They were derived from the wide and already consolidated Akiyoshiid. Therefore the Shidaka series can not be coeval to the Yakuno series, which the latter represents a flysch stage and shows that there was almost no significant geographic relief in the Yakuno epoch. The Inai type banded slate and carbonates cannot be accumulated in the narrow post-orogenic basin. The most striking difference between the Yakuno and Shidaka series probably lies in the constituents of sediments and the provenance. The Yakuno sandstone received the fragments from the non-metamorphosed Palaeozoic rocks, while in the Shidaka series, sediments were transported from the axial zone of the Akiyoshiiden, which was occupied by andesitic, granitic and metamorphic rocks as well as non-metamorphosed rocks as in the Mine epoch. If there were strong topographic relieves of the Akiyoshiid already in the Yakuno epoch, rock fragments must be included in the Yakuno series. The Yakuno-series is a product of the stage "before the appearance

of the relief", while the Shidaka series received sediments from the ragged Akiyoshiid. Features of rhythmic sediments, texture and matrix of conglomerates and sandstones and other aspects of sediments depend largely upon the instability of the basin and its hinterland. Between the Shidaka and Mine series, which are the post-orogenic sediments (s. l.), the former represents slower deposition than the latter. In other words, the Shidaka series was accumulated when the crust became more stable than the Mine epoch. Through ·Asa, Mine and Nariwa areas, the Mine series reveals similar aspects characterized by coal measure rhythm and shooting sediments of the Momonoki type. Therefore, if the Shidaka is coeval to the Mine series, it must bear similar aspects,· because the Shidaka bears also conglomerates and coal seams and it is situated near Nariwa area. However, the Shidaka is neither rhythmic nor bearing the deltaic sediments of the Momonoki type (pl. XV, fig. 7), although the Shidaka sandstone resembles the Hinabata sandstone in Nariwa area. On the other hand conglomerates and sandstones of the Miharaiyama formation closely resemble those of the Liassic Kuruma series. Therefore it is probable, that the Shidaka series is younger than the Mine series and older than the Kuruma series. It is probably Noric, if not Rhaetic. This conclusion agrees with the KAMBE's (1950) and KOBAYASHI's (1959).

3. Kuruma series

3.1. General geology (KOBAYASHI, KONISHI, SATO, HAYAMI & TOKUYAMA, 1957)

The Liassic Kuruma series is more than 8000 m thick and lies on the Palaeozoic semi-schists with unconformity. It is subdivided into the Jogodani, Kitamatadani, Negoya, Teradani, Shinatani, Otakidani and Mizukamidani formations in ascending order, where the Teredani and Otakidani formations are open-sea deposits containing ammonites, while the remainder is basin deposits, with pelecypods. It is a coarse and thick formation neither rhythmic nor thin bedded, but massive and forms a continuous sequence.

In Daira area, in the west, the series forms a syncline open to the northeast. Sediments are relatively fine and well represented by black mudstone and shale, containing *Eomiodon*-banks in the east, while they merge westward into coarse sandstone and conglomerate. Sometimes deltaic conglomerates are intercalated in the upper Negoya formation. Sandstones are arenitic, containing numerous rock fragments and poor matrix in the west, while they are cemented with muddy or bituminous matrix in the east.

In the transitional zone between the marginal (western) and central (eastern) part of the basin, there are cross-beddings of a large scale. Thick and massive sandstone beds (each about 1 m thick) thin out suddenly to the southeast. The arenitic sandstone in the west is gradually replaced by fine grained mudstone in the east. Thus the facies changes remarkably. The Kuruma series is, however, massive and relatively monotonous through the column, except for these horizontal changes. Therefore it is rather hard to zonate the series except for the marine bands of the Teradani and Otakidani forma-

tions. Although the sediments are monotonous through the series, constituents gradually change upward from the Kitamatadani and Negoya to the Mizukamidani formation.

The Negoya formation contains numerous fragments of non-metamorphosed Palaeozoic rocks. Sometimes shaly patches are aggregated in the western part of the basin; they were reworked from the contemporaneous sediments in the west. Fragments of granitic or gneissose rocks are found in sandstone of the upper Negoya and lower Shinatani formations, although no such gneissose rocks are found in any conglomerate of the two formations. The arenite is characterized by numerous fragments of Palaeozoic rocks, attaining 30% in the upper Negoya formation. The sandstone changes upward suddenly into arkose above two thick conglomerates, although cherty fragments are found in the lower Mizukamidani formation. It is interesting that pebbles of granitic rocks appear first in the two conglomerates of the lower Mizukamidani. They are absent or insignificant in the Shinatani and subjacent formations. The Mizukamidani formation is characterized by massive and coarse containing fragments of granite with microcline, although it carries minute chert fragments.

3.2. Remarks on the Kuruma series

The Kuruma series reveals a complete cycle of denudation. For the lower Kuruma series the provenance of its material was Palaeozoic rocks, which may have been a kind of roof pendant on the granitic rocks in the axial zone of the Akiyoshi folded mountains. Toward the upper Kuruma the relative volume of granitic rocks to the total sediments increases, until the sediments are completely occupied by arkose in the Mizukamidani formation.

The similar lithologic change is found also in the Mine series. The Hirabara formation received the sediments from the non-metamorphosed Palaeozoic rocks, and the Momonoki and Aso formations from the Akiyoshi axis, which is composed of andesitic rock, the Sangun schists and Yamaguchi Palaeozoic rocks beside the Funatsu granitic rocks in Hida area. The lithologic change is, however, abrupt in the Mine series, because the Hirabara formation is a filling of the local depression, while the Momonoki is a shooting sediment, suddenly transported from the elevating hinterland.

The facies change in the Kuruma series is gradual, because it is a sequence of basin sediments. In the Kuruma epoch, there was neither sudden subsidence of the basin nor intense elevation of the hinterland as seen in the Mine series. The monotonous arkose of the Mizukamidani formation indicates extensive granitic rocks in the hinterland. In the Mine epoch the relief of the hinterland is more steep and complicated than in the Kuruma epoch, seeing that the Mine series contains numerous fragments of andesites and subordinate schists, shales and cherts beside granitic rocks. Since granitic rocks occupies 40-70% in the Momonoki and Aso sandstones, they belong to lithic arenite, instead of arkose. On the other hand the Mizukamidani sandstone is a complete arkose, which suggests a more simple and extensive hinterland of

granitic rocks. Such an extensive granitic rocks as presumed from the Mizukamidani sandstone must owe the Rhaetic culmination of the Toyogataki phase, through which the axial core, i. e. the Akiyoshiid was profoundly dissected. The granitic rock has been exposed on the surface through the subsequent denudation of the Kuruma epoch.

Similar denudation is also demonstrated in the Cretaceous Onogawa and Izumi series, i. e. the post-orogenic subgeosyncline of the Sakawa orogeny. The lower Izumi sandstone, for example in the Warazuhata and Kinyuji formations (KOBAYASHI, 1930), contains numerous chert and shale of Palaeozoic rocks, while the upper Izumi sandstone or the Kuzuhata sandstone is almost arkosic.

The Kuruma series is coarse and extraordinally thick. It is however, neither rhythmic nor thin bedded as the Mine series, but massive and fairly monotonous through the series. The lithology and fossil assemblage of the Kuruma series reveal an embayment. It was stagnant and bituminous in the central part, while it received coarse sediments on the western side, where the water was somewhat agitated. Cross-bedding of a large scale and sometimes slide conglomerates are found in the transitional zone between the marginal and central facies, indicating the slope on the bottom. The lithofacies changes little through the column of the Kuruma series, except for the lithic sandstone in the lower part merging into arkose, although the horizontal change in lithology is remarkable. The fact reveals that the basin maintained similar embayment through the Kuruma epoch, except for the twice or thrice invasions, represented by ammonite beds. Therefore it is evident that the subsidence of the basin was balanced with the supply of sediments.

It is noticeable that the similar sediments can be found in the post-orogenic sediments of the Sakawa orogeny. The upper Cretaceous Onogawa series in Kyushu is about 13000 m thick (MATSUMOTO, 1936). It is coarse, massive and fairly monotonous through the series. The lower Onogawa series reveals an embayment, bearing the bituminous sediments as in the Kuruma series, although the upper Onogawa series displays a more or less wider basin than the lower Onogawa series, and it developed into the Izumi subgeosyncline.

Conclusion

In this paper the orogenic cycle is discussed from the standpoint of sedimentary facies. It is divided into the following five stages:

1. The *pre-orogenic* stage is represented by the sediments of geosyncline. This stage occupies the earlier half of the cycle. During the stage sedimentary facies are arranged in several zones by the subterraneous crustal movements.

2. The *prorogenic* stage corresponds with the "Flysch-stage" in the Alpine cycle., in which the geosyncline was differenciated into several partial basins. Later they became narrow as a result of embryonic foldings or "Stammfaltungen". The contemporaneous sediments record the strong and abrupt subsidence of the basin, which tended intense in the later stage. The narrowing of the basin and the mode of accumulation suggest the strong

compression in the crust. Seeing that the sediments are purely marine, the geographic relieves were yet insignificant, if present, in this stage.

3. The *eu-orogenic* stage is links between the Flysch-stage and Molasse, during which strong and rapid relieves of the folded mountains were built up. The early stage is represented by the flysch-like sediments, which passes later suddenly into the molasse-like facies. Incidentally the basins were narrowed and the marine basins tended into terrestrial. When compression of the crust came to its climax, the large and steep relieves of folded mountains were made.

4. In the *meta-orogenic* stage folded mountains were elevated and completed. Seeing that the meta-orogenic sediments are coarse, thick and characterized by frequent change in lithology, the crust was yet very unstable. The meta-orogenic basins were formed either in the intermontane zone or the fore-land of the mobile folded mountains. A large mass of terrestrial matter is transported from the back-ground and filled the basin. The meta-orogenic sediments include epi-cyclic sediments and coarse conglomerates of fluvial shooting as in the Mine series, Alpine Molasse and the Westphalian of the Saar region. The Rigi-rhythm and alluvial fans of the Nagelfluh in the Molasse are explained to have been produced by the repeated thrusting in the Alps. Through the thrusting and folding the compression of the crust may have been relieved. The crustal movements of the mountainland seems to have become weak, because the contemporaneous sediments became monotonous and fine.

5. In the *post-orogenic* stage the folded mountains were dissected and levelled. Since the crust has already been stable, the post-orogenic sediments are represented by the stable shelf-facies around the folded mountains. A new subsiding basin was added in the mountains through the decomposition of the axial zone. At first the subsidence was local and intense, but became weak, incidentally the small basin tending larger.

6. In the pre- and prorogenic stages crustal movements become intense and the basin becoming narrower in the later stage in consequence with the strong compression in the crust. After the eu-orogeny two new sedimentary basins were formed in the foreland and the intermontane region of the folded montains. They are narrow and controlled by intense crustal movements at first, but later the basin becomes widened and the crust becomes stable.

The change in the palaeogeographic condition and crustal movements are evidenced in the megascopic as well as microscopic features and properties of sediments.

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Granite

Porphyrite

Ink stone

Intercalation of shale   A

Coal seam

Sandstone

Omine coal measures   N

Momonoki delta

Mugikawa coal measures

Third cycle

Second cycle

First cycle

Takiguchi formation

Atsu series

Yamaguchi group

Sangun group

As: Aso, Ga: Ganpi, Hi:Hira
Ho: Hoho, Im: Imayama, Is: Ie
kata, Ku: Kuwabara, Mi:Mita
Mo: Momonoki, Mt: Mitsusu
Od: Oda, Oj: Ojigase, Ok: Ok
Om: Omine, Sh: Shiraiwa, Si
gahara, So: Sonose, Ta: Ta
Tk: Takiguchi.

A. TOKUYAMA

Triassic Orogenic Sediments

Plate XV

Explanation of Plate XV

Conglomerates and coal seams of Momonoki and Shidaka formations

Figs. 1, 2. Fore-set bed of the Momonoki delta, along the high way near the Hirabara-pond, NE of Momonoki, Mine city.

Fig. 3. Conglomerate of the lateral facies (bottom-set bed) of the same delta, near Ofuku.

Fig. 4. Coal seam of the lateral facies of the same delta, near Ofuku.

Fig. 5. Coal seam in the Omine coal measures, along the high way NE of Momonoki.

Fig. 6. A cycle of the Omine-rhythm, a: coarse sandstone, b: alternation of mudstone and sandstone, c: coal seam, a′: conglomerate of the next cycle.

Fig. 7. Conglomerate of the lower Shidaka series, near Yuri, Shidaka.
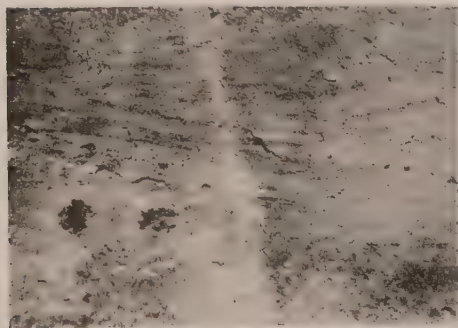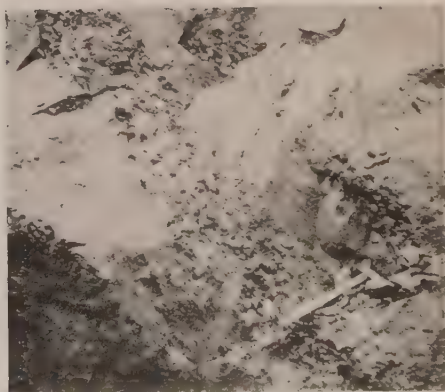
Plate XVI

Explanation of Plate XVI

Alternation of the bottom-set bed of the Mogamiyama delta and coal measure rhythm of the Mogamiyama formation in Nariwa area.

Figs. 1–3.   Three stages of an oscillation.

    Fig. 1: transgressive stage; 2: inundation stage; 3: regressive stage. Loc.: East of Hinabata, Nariwa.

Fig. 4.   A shaly intercalation showing the three stages; a: transgressive, b: inundation, and c: regressive stage. Loc.: East of Hinabata.

Fig. 5.   Alternation of sandstone and mudstone in the Mogamiyama rhythm.

1

3

2

4

5

A. Tokuyama

Triassic Orogenic Sediments

Plate XVII

Explanation of Plate XVII

Lateral change of the two Aso sandstones.

Figs. 1–4. A-sandstone changes from northern immature form (1) to southern mature form. This sandstone is characterized by paucity of matrix. 1: Shimizuda, 2: Mishime, 3: Yuguchi, 4: Imayama.

Figs. 5–8. B-sandstone changes from North (5) to South (8). This sandstone is characterized by more matrix and more angular and ill-sorted fragments than A-sandstone. The matrix in the northern part is characterized by andesite-fragments, which changes sowthwards into cherty matrix. 5: Okamukai, 6: Aso, 7: East of Sonose, 8: West Imayama.

(Sections except 2 are crossed Nicol, ×40).

1

2

3

4

5

6

7
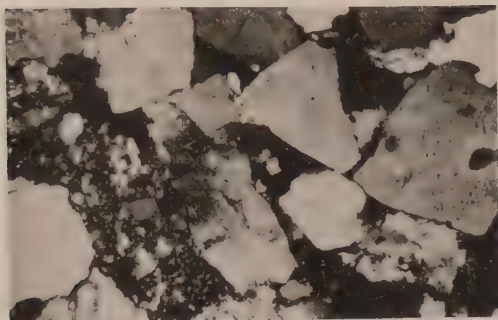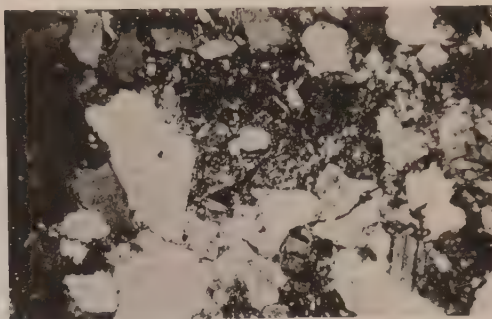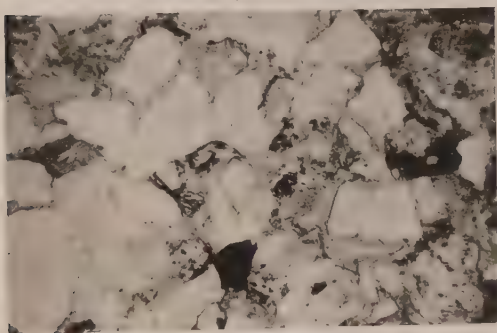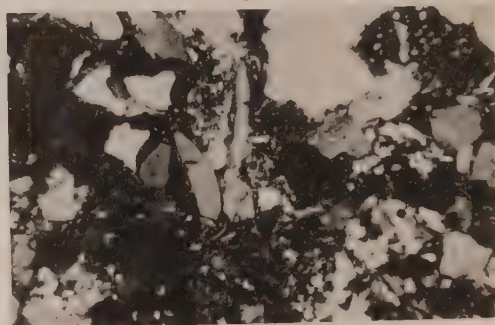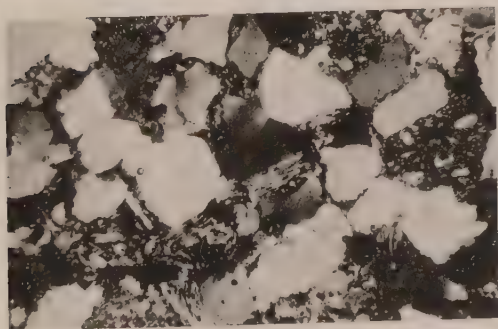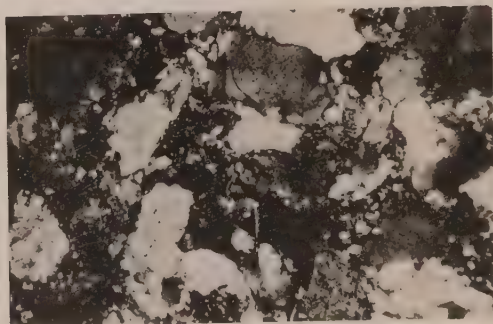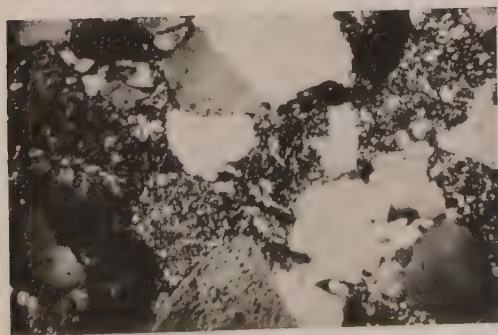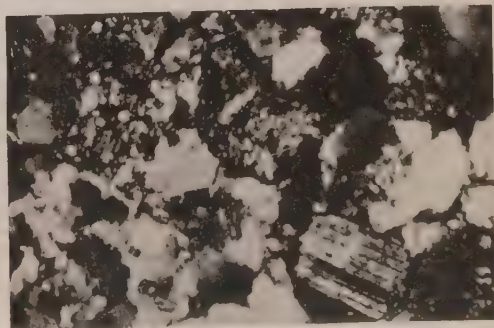
8

A. TOKUYAMA

Permian and Triassic Orogenic Sediments

Plate XVIII

Explanation of Plate XVIII

Sandstones of prorogenic sediments.

Figs. 1–4. Graywackes of the Kuma series.

    Figs. 1, 2: Graywackes from the middle Kuma series, near Tsuru, Kuma, middle Kyushu.

    Fig. 3: Graywacke in the graded bed of the Kuma series in Sakuradani area, at Sakashu, Tokushima Pref.

    Fig. 4: Graywacke from the middle Kuma series in Sakuradani area, at Sakuradani, south of Sakashu.

Figs. 5–7. Quartz-sandstones of the Inai series.

    Fig. 5: Hiraiso sandstone (quartzose sandstone with calcareous matrix) from the base of the Inai series at Tate, near Isatomae, Miyagi Pref.

    Fig. 6: Hiraiso sandstone at Aonosawa, north of Kesennuma, Iwate Pref.

    Fig. 7: Kazakoshi sandstone at Aonosawa (crossed Nicol).

Fig. 8. Sandstone of the Yakuno series in Maizuru area. This shows an intermediate form between graywacke and Hiraiso sandstone. Loc. W of Nukada, Maizuru area, Hyogo Pref.
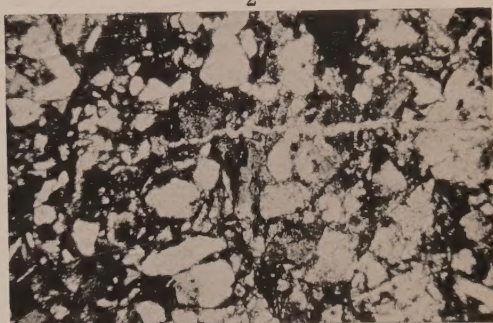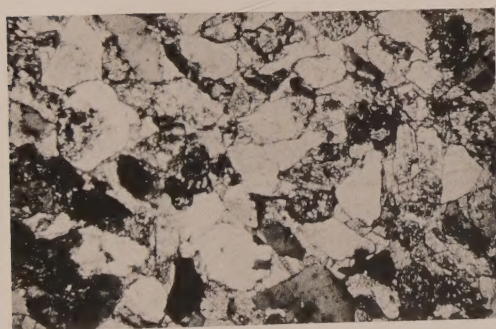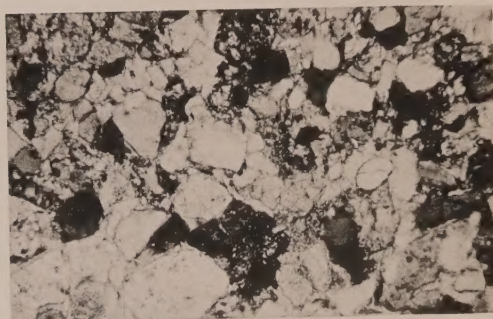
(Sections except 3, 7 and 8 are opened Nicol, ×40).